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RESEARCH MEMORANDUM

FLIGHT INVESTIGATION OF THE AERODYNAMIC DERIVATIVES AND PERFORMANCE OF CONTROL SYSTEMS OF TWO FULL-SCALE GUIDED BOMBS

By Ernest C. Seaberg and Edward S. Geller

Langley Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The aerodynamic stability derivatives and the pitch and yaw control effectiveness of two full-scale guided bombs were determined over the Mach number range of approximately 0.55 to 1.0 by free-flight drop tests. The longitudinal and lateral aerodynamic information was determined from the responses to programed pulsing sequences of the pitch and yaw controls, and the adequacy of the flicker automatic roll control was also checked under these conditions.

The results of the present flight investigations dealing with the measurement of the stability derivatives agree very well with unpublished wind-tunnel results, and the flight-test responses can be recomputed with a fair degree of accuracy through the use of the aerodynamic constants obtained from the flight data. It is, therefore, reasonable to assume that it would be valid to use the stability derivatives for further flight simulator studies.

Although several operational difficulties were experienced in preparing the bombs for flight test, the over-all performance of the bombs during the flight tests was considered to be satisfactory. In particular, the performance of the flicker automatic roll control was considered to be very good, and it is shown that the pitch and yaw control vanes are effective in producing lift and side forces of the order of one times the acceleration due to gravity.

INTRODUCTION

The Langley Pilotless Aircraft Research Division with the cooperation of the Langley Instrument Research Division and the Langley Flight

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Research Division conducted two successful free-flight drop tests of a full-scale guided bomb. The purpose of these tests was to determine flight performance information and to measure the aerodynamic derivatives of the bomb for use in flight simulation studies.

Since the nature of these tests did not necessitate the use of the guidance system, it was omitted from the bombs tested at Langley. The pitch and yaw controls were simply pulsed in programed sequences as step-function inputs during the free-flight drop tests, and flight data in the form of output transient responses were obtained. The methods presented in reference 1 were used to evaluate these flight data. Each bomb contained a flicker automatic roll stabilization system. The present flight tests served to determine the adequacy of this system and its ability to overcome the induced roll caused by simultaneously pulsing the bomb in pitch and yaw.

SYMBOLS

a_n	normal acceleration, g units
a_t	transverse acceleration, g units
a_l	longitudinal acceleration, g units
$\bar{c}$	wing mean aerodynamic chord (1.65 feet)
M	Mach number
q	dynamic pressure, lb/sq ft; or pitching angular velocity, deg/sec
r	yawing angular velocity, deg/sec
g	acceleration due to gravity, ft/sec^2
t	time, sec
V	velocity of bomb, fps
S	total wing area in one plane (4.11 sq ft)
W	weight
m	mass
I_x	moment of inertia [redacted]itudinal body axis

[redacted]

I_y moment of inertia about the transverse body axis

I_z moment of inertia about the normal body axis

α angle of attack, deg

β angle of sideslip, deg

τ roll-servo time-lag factor, sec

λ rate-gyroscope rate factor, deg/deg/sec

$\dot{\alpha} = \frac{d\alpha}{dt}$, deg/sec

$\dot{\beta} = \frac{d\beta}{dt}$, deg/sec

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_Y side-force coefficient, $\frac{\text{Side force}}{qS}$

$C_{L_{trim}}$ C_L based on trim lift force

$C_{Y_{trim}}$ C_Y based on trim side force

C_D drag coefficient, $\frac{\text{Total drag}}{qS}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qS\bar{c}}$

$C_{L_{\alpha}} = \frac{\partial C_L}{\partial \alpha}$, per deg

$C_{Y_{\beta}} = \frac{\partial C_Y}{\partial \beta}$, per deg

$C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha}$, per deg

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$, per deg

$C_{m_q} + C_{m_{\dot{\alpha}}} = \frac{\partial C_m}{\partial \frac{qc}{2V}} + \frac{\partial C_m}{\partial \frac{\dot{\alpha}c}{2V}}$, per deg

$C_{n_r} - C_{n_{\dot{\beta}}} = \frac{\partial C_n}{\partial \frac{rc}{2V}} - \frac{\partial C_n}{\partial \frac{\dot{\beta}c}{2V}}$, per deg

METHOD AND APPARATUS

Bomb Description

Photographs and a sketch of one of the bombs used in the present tests are shown in figure 1. This missile contains a flicker automatic roll stabilization system and a pitch and yaw guidance system. The guidance system, however, was not included in the bombs reported on herein. The missile consisted of a nose and tail section attached to a dummy general-purpose bomb. The nose section is made to house the guidance system and the pitch and yaw controls, whereas the tail section contains the roll stabilization system and cruciform stabilizing fins with trailing-edge ailerons.

Roll Autopilot

Automatic roll control was obtained through the use of an Azon gyro unit which combined the error signal from displacement plus rate gryoscopes to actuate the ailerons for corrective control through the use of a flicker pneumatic servomotor. A flap-type trailing-edge aileron was attached to each of the four stabilizing fins as shown in figure 1(b). One aileron was driven directly by the servomotor, and the other three were slaved to the driven aileron through the use of a cable and pulley arrangement. The half-amplitude of the flicker aileron deflection was set at approximately 8° for each aileron.

Pitch and Yaw Controls

Operationally the bomb is controlled in pitch and yaw by means of four pneumatically operated vanes located in the nose. These pitch and yaw control vanes are unique in shape in that from the front view they are approximately quarter-arcs of a 14.75-inch-diameter circle. These vanes are normally retracted within the contour of the airframe and their line of actuation is parallel to the missile longitudinal axis. Details of a control vane are shown in figure 1(b), and figure 1(c) is a photograph of the bomb nose with two control vanes extended. When a course correction is called for, the proper vane is extended forward a distance of approximately 3 inches. The center line of this actuation is interdigitated 45° with the main stabilizing fins. For the present tests, the upper pitch vane and the left adjacent yaw vane were pulsed in programed sequences, as shown in figure 2, and the other two vanes were locked in the retracted position. It is noted that the pulsing sequence shown in figure 2(b) for the second bomb is approximately twice the frequency and in the reverse order of the pulsing sequence shown in figure 2(a) for the first bomb. This was done to increase the amount of data obtained over the Mach number range and to obtain a wider variety of pulsing information.

Instrumentation

Each bomb was equipped with an NACA ten-channel telemeter which transmitted a continuous record of the normal, longitudinal, and transverse accelerations; angle of attack; angle of sideslip; angle of roll; total-head pressure; pitch-control-vane position; yaw-control-vane position; and aileron deflection. Most of the telemeter instruments used to obtain this information and the battery power supply were mounted on a hatch cut in the top of the bomb body, as shown in figure 3.

Angle of attack and angle of sideslip were measured by a free-floating vane extended from the nose on a sting. This instrument is designed to measure the usual stability-axis-system angle of attack and angle of sideslip; that is, α is measured in the vertical body plane of symmetry and β in a plane inclined from the horizontal body plane of symmetry by the angle of attack and perpendicular to the vertical body plane of symmetry. Total pressure was measured by a total-pressure tube extended below the sting. The positions of the angle-of-attack and angle-of-sideslip vane and the total-pressure tube are shown in figure 1(a).

Operational bombs obtain their electrical power supply from the windmill-propeller-driven generator located in the tail as shown in figure 1. This source of electrical power, however, was not used for

the instrumentation in the Langley free-flight drop tests. Instead, a simulated electrical load was placed across the generator output and the necessary electrical power for the tests was obtained from batteries.

The bomb trajectories were determined through use of a modified SCR-584 radar tracking unit. A radiosonde released at the time of flight measured temperatures, atmospheric pressures, and was tracked to obtain wind information through the flight-test altitude range. The wind information is given in table I.

Preflight Measurements and Checks

The values determined by preflight measurements are as follows:

	Bomb 1	Bomb 2
Weight, lb	1167	1170
Moments of inertia:		
I_X, slug-ft^2	16	16
I_Y, I_Z, slug-ft^2	107	106
Center-of-gravity location, from base of nose sting, in.	$37\frac{15}{16}$	38
Aileron deflection, half-amplitude, deg	7.9	8.2
Roll rate gyroscope rate factor, λ, deg/deg/sec	0.141	0.140
Average time lag between gyro signal and aileron actuation, τ, sec	0.054	0.045

In addition to the foregoing preflight measurements, the instrumentation and operational components of each bomb were cold checked at a temperature of approximately -60° F by using the stratochamber at the Langley Instrument Research Division. A bench check of each Azon roll-control gyro unit was also made mainly to check the free gyroscope drift under dynamic conditions. This drift was minimized to within 1° per minute by careful adjustment of the gimbal bearings.

Flight Test

The free-flight drop tests were conducted with a North American XF-82, Twin Mustang, as the parent aircraft. The bombs were mounted under the wing between the fuselages by using a release cable arrangement.

The bombs were released in an approximately level attitude, and the following conditions were observed at the instant of release:

	Bomb 1	Bomb 2
Altitude, ft	36,000	36,000
Mach number	0.550	0.525
True airspeed, ft/sec	530	530
Free-air temperature, °F	-64	-55

Accuracy

It is impossible to state precisely the limits of accuracy of each quantity derived from free-flight tests. The probable accuracy of the various aerodynamic derivatives derived from the test results depends on the number of measured quantities involved, the method employed to evaluate a particular derivative, and in this case the extreme variation of the atmospheric conditions would be an influencing factor in determining accuracy. For these reasons, values of force derivatives are considered to be more accurate than static stability or damping derivatives. It is also believed that the stability derivatives are more accurately determined in the latter part of each flight test where the Mach number and density are generally higher. Although the drag values presented are dependent on more measured quantities, they are considered to be of accuracy comparable to that of the force derivatives, since the determination of C_D is not dependent on a combination of mathematical and graphical procedures.

In general, the absolute value of any telemetered measurement can possibly be in error by 2 percent of the total calibrated instrument range. If the accumulation of errors is considered in a discussion of trim lift or side force, the accuracy will be considerably better for control pulses at low altitude where larger measured quantities are dealt with.

RESULTS AND DISCUSSION

Performance Information

Statistical.- The trajectories shown in figure 4 are three-dimensional plots of each bomb's flight path obtained from ground-tracking radar data. A horizontal projection of each trajectory is shown for space reference and the reference axes are oriented to the aircraft flight path, that is, the aircraft line of flight, is essentially constant at 36,000 feet and is in the plane formed by altitude and horizontal range axes.

Velocity and Mach number time histories are shown in figure 5. A peak of $M = 0.99$ was obtained at 42 seconds for the first bomb, and a peak of 0.92 was obtained at 44 seconds for the second bomb. Reference to figure 4 indicates that these peaks occurred at altitudes of approximately 13,500 and 11,000 feet.

Servo operation.- Unpublished data from previous stratochamber tests of pneumatic servos, such as those contained in the bombs used in the present tests, indicated that the servo valves might freeze up when subjected to extreme cold conditions. Although the stratochamber cold check of the first bomb did not indicate a malfunction in the servo system, these servos did freeze up at altitude on a previous attempt to drop-test this bomb. Evidence to indicate excessive leakage in the penumatic supply was also obtained at this time. Malfunction of the servos of the second bomb was obtained in stratochamber tests. It was, therefore, found necessary to add heaters to all servos of both bombs to assure satisfactory operation of the pneumatic components during the present flight tests. These heaters are very similar to those used for Langley telemeter components such as accelerometers, pressure pickups, gyro pickups, and so forth, which are subject to viscosity effects or sensitivity changes due to cold. The telemetered flight data indicated that servo operation was entirely satisfactory during the present flight tests. It is believed that the previous malfunctions were caused by moisture condensing in the servo valves causing them to freeze up after they had cold soaked in the stratochamber or at altitude.

Roll Control Operation

General comments.- The over-all operation of the flicker-roll autopilot was considered to be entirely satisfactory for both bombs. For the second drop test the parent aircraft was in about an 11° right bank when the displacement gyro was uncaged, which resulted in the bomb trimming at about 11° or 12° in roll for the remainder of the flight test. This change of roll trim reference angle, however, is not considered to affect seriously the other flight data obtained.

Time histories.- The telemeter record of roll angle against time obtained for the first bomb indicated large bank angles (up to 70°) immediately after release. These damped to approximately $\pm 2^{\circ}$ at 12 seconds, and the amplitude of the roll oscillations kept this order of magnitude for the remainder of the flight. The frequency of these oscillations increased from approximately 1.5 cps at 12 seconds to 4.5 cps at impact. The second bomb behaved somewhat differently in that the initial roll angles obtained after release were only about $\pm 10^{\circ}$ from the trim value, and these damped to about $\pm 1^{\circ}$ in approximately 4 seconds. This oscillation amplitude remained fairly constant until later in the flight when

increases up to ±2° were obtained during a simultaneous pitch and yaw pulse condition. The frequency of these roll oscillations increased from approximately 2.5 cps at 4 seconds to 5.2 cps at impact. Reference to the preflight measurements given previously indicates that the second bomb had a somewhat larger aileron deflection and shorter average time lag between gyro signal and aileron deflection, which accounts for its oscillating in roll at generally smaller amplitudes and higher frequencies. Actual portions of the roll-angle and aileron-deflection telemeter records are reproduced in figure 6. It is of interest here to note the effect of a simultaneous pitch and yaw pulse. These occurred at approximately 57 seconds for the first bomb (fig. 6(a)) and at approximately 45.5 seconds for the second bomb (fig. 6(b)). In reference 2 it was indicated that it might be difficult for a cruciform configuration with flap-type ailerons to achieve adequate roll control when subjected to rolling moments induced by simultaneous pitching and yawing. This, however, was not found to be the case for the bombs reported on herein. The data shown in figure 6 indicate some disturbance for this case but no real adverse effects. Even the slight trim change $\left(\text{about } 2\frac{1}{2}^{\circ}\right)$ obtained for the second bomb is not considered serious.

Aerodynamic Characteristics

Time histories.- Typical time histories of angle of attack, normal acceleration, angle of sideslip, and transverse acceleration obtained from telemetered flight data are shown in figure 7. These results indicate that there was considerable aerodynamic out-of-trim effect present in the pitch plane for the first bomb, and, in general, the transient oscillations of the second bomb proved to be smoother, showing also some increase in trim lift and side force. As can be seen from figure 7(c), the yaw oscillations of the first bomb were particularly erratic. In the final plot of figure 7(c), for instance, it appears that a secondary oscillation is superimposed on the yaw transients. An examination of the roll data for the same time interval shown previously in figure 6(a) indicates that the secondary yaw oscillation is close to the roll frequency. There is, therefore, a possibility that the yaw motion is at least partially influenced by roll and pitch coupling. Although the data are not shown, evidence to indicate that coupling existed between the yaw and roll motions was obtained at the same time. The out-of-trim effect of the first bomb is evident during the condition "pitch and yaw control vane in" shown in figure 7(a) where the bomb did not trim out at zero α or a_n. This out-of-trim effect is also evident at the start of the condition "pitch control vane out" in the same figure since the bomb was trimmed out at about $a_n = 0.64g$ and $\alpha = 4.6^{\circ}$ at this point. Since the out-of-trim accelerations in some cases were about 60 percent of the pitch control effectiveness and the transient

oscillations were not as smooth for the first bomb, special efforts were made in preparing the second bomb for flight test to assure that the nose and tail sections were alined with and rigidly attached to the main bomb body, and the fin alinement with the body axes was also checked.

In connection with the rigidity between the main bomb body and the nose section, it is noted here that an examination of the first bomb after it had been taken to altitude on an earlier drop-test attempt revealed that the nose-casting mounting bolts were very loose. It is probable that vibration of the parent aircraft caused this. Although it can only be surmised at this time, there is a possibility that these bolts may have loosened again during the climb to 36,000 feet prior to the actual drop causing some loss in control effectiveness and could have been partially responsible for the erratic transient oscillations obtained during the flight test.

The flight data obtained for the second bomb did not indicate any appreciable pitch out-of-trim values; however, in one case the out-of-trim error in yaw appeared to be about 3.8° in sideslip angle and 0.3g in transverse acceleration. The results of ballistic calibration tests on similar roll-stabilized bombs showed ranges greater than vacuum drop for some cases, indicating lift forces were present although, for these tests, the pitch and yaw control vanes were entirely omitted from the bombs.

The effectiveness of the pitch and yaw control vanes in producing lift and side forces can be seen in figure 7. The data shown can be summarized as follows:

Figure	Bomb	Pulse condition	Approximate change in trim a_n, g	Approximate change in trim a_t, g
7(a)	1	Pitch control vane out	1	---
7(d)	2	Yaw control vane out	---	1.4
7(c)	1	Pitch and yaw control vane out (57 to 60.2 sec)	---	.6
7(b)	2	Pitch and yaw control vane out	.8	---

As is indicated here and particularly in figure 7(d), more effectiveness is obtained when a control vane is extended by itself. It is believed that the accelerations shown would be fairly effective in executing

normal course corrections which might be dictated by a guidance system during a guided drop. The data obtained from the present flight tests show that the control vanes are effective in executing turns of the order of 1 g.

Trim curves.- Values of trim lift and side-force coefficient, which were obtained from steady-state lift and side-force data, are plotted as functions of Mach number in figure 8. The adverse out-of-trim effect obtained in pitch for the first bomb is shown by the rapid rise in $C_{L_{trim}}$ above $M = 0.9$ in figure 8(a). In general, the change in the $C_{L_{trim}}$ and $C_{Y_{trim}}$ levels obtained for the second bomb with one or both control vanes extended appears to be somewhat higher than the change obtained for the first bomb; therefore, an increase in control effectiveness was indicated.

The difference in the adverse out-of-trim effect, the appearance of the transient oscillations, and the control effectiveness obtained between the two bombs flight tested in this investigation seems to indicate that the alinement and rigidity of the nose and tail sections of this type of missile are critical.

Aerodynamic derivatives.- The results of an evaluation of the telemetered flight data obtained from the present free-flight drop tests expressed in terms of the longitudinal and lateral aerodynamic derivatives plotted as functions of Mach number are presented in figures 9 to 14, and the variation of the pitch and yaw aerodynamic-center positions with respect to the center of gravity, plotted as a function of Mach number, is shown in figure 15. Except for the damping derivatives for which only meager wind-tunnel data were available, a comparison is made between curves obtained from an evaluation of unpublished wind-tunnel data and the flight data obtained from the present tests. In general, the agreement between the results obtained from an evaluation of the wind-tunnel data and the present flight-test data appears to be very good.

The flight-test-data evaluation presented in this section is of necessity based on a linear two-degree-of-freedom analysis. Since in some cases the transients from which the derivatives were evaluated appeared to be influenced by roll coupling, some discretion was necessary in employing the two-degree-of-freedom evaluation. In the cases where flight-test responses were particularly erratic, for instance, it was not possible to determine the damping derivative adequately and, since the static-stability derivative is predominately a function of the oscillating frequency, it was occasionally difficult to evaluate because the oscillation appeared to consist of more than one harmonic mode.

Although the general agreement between the wind-tunnel, bomb 1, and bomb 2 data is considered good, some discrepancies can be noted. The derivative C_{m_α} for bomb 1 with pitch control vane out (fig. 11(b)), for instance, is generally at a higher level than C_{n_β} for bomb 2 with yaw control vane out (fig. 12(b)). It is probable that this can be partially explained by geometric differences between the two bombs and data reduction or instrumentation inaccuracies. It is, however, more probable that the difference in this case can be attributed to nonlinearities of the pitching- and yawing-moment curves. With regard to figure 11(d), it is also probable that the discrepancies can be attributed to nonlinear pitching-moment curves.

Drag.- The primary purpose of the free-flight tests reported on herein was to determine the longitudinal and lateral stability and control characteristics; however, the drag characteristics of the second bomb were also measured and are presented herein.

During each flight test the inclination of the longitudinal body axis to the relative-wind vector was measured by the angle-of-attack, angle-of-sideslip vane and the forces acting along the three body axes were measured by accelerometers. The following equation, which nondimensionalizes and sums these forces in the direction of the relative wind, was used to evaluate the drag coefficient:

$$C_D = \left(-a_l \cos \alpha \cos \beta + a_n \sin \alpha \cos \beta + a_t \sin \beta\right)\frac{W}{qS}$$

The variation of total drag coefficient with Mach number obtained for the second bomb is presented in figure 16. A definite increase in C_D with increasing Mach number is apparent from this figure. An increase in C_D is also obtained when one or both of the pitch and yaw control vanes are extended, which is mainly due to the increase in trim angle of attack or sideslip. For some values of Mach number a pronounced spread in the data is shown. In these cases sufficient data were available to evaluate the drag coefficient over the relatively large range of oscillation amplitudes about the trim value of α or β.

Comparison of flight-test and calculated responses.- In figure 17 a comparison is made between some of the actual angle-of-attack and angle-of-sideslip responses obtained from telemetered flight data and those calculated using the flight-test derivatives in the standard two-degree-of-freedom equations of motion. The lift and moment forcing functions used for the calculations were based on the initial and steady-state values of the free-flight transient responses and the flight conditions measured during the drop tests were also introduced into the equations in order to obtain a solution. Only two cases are shown for the

second bomb; however, many more were calculated, and in general the qualitative agreement between the flight data and calculated responses was very good. The slight differences obtained, which can be attributed mainly to nonlinearities in the stability derivatives which necessarily are averaged out in an investigation of this type, are not considered serious. The use of the stability derivatives presented herein for further flight simulator studies is, therefore, believed to be justified.

Vibration or buffet data.- Throughout the entire flight of both bombs high-frequency oscillations of varying intensity were superimposed on the accelerometer telemeter records. The corresponding flight conditions and frequency and amplitude of several of these oscillations obtained from the flight data of the first bomb are listed in table II. Since the amplitudes given in this table had to be based only on estimates of the attenuation characteristics of the accelerometers, a special high-natural-frequency transverse accelerometer was included in the instrumentation of the second bomb. The attenuation characteristics of this accelerometer were measured prior to the flight test, and the oscillation data obtained based on these attenuation characteristics are listed in table III. Actual portions of the telemeter records are reproduced in figure 18 to illustrate this vibration information more clearly. It is noted that these oscillations resemble what is normally called buffeting.

CONCLUSIONS

The conclusions arrived at as a result of the free-flight bomb-drop tests reported on herein are as follows:

1. In general, the agreement between the aerodynamic derivatives obtained from the present flight tests and those obtained from an evaluation of the available wind-tunnel data is very good. It has also been determined that the solution of the standard two-degree-of-freedom equation of motion using the flight-test derivatives together with the other necessary constants based on the flight data yield calculated transient responses which resemble the flight-test responses very closely except for some instances when particularly erratic responses were obtained for the first bomb. The use of the stability derivatives presented herein for further flight simulator studies is, therefore, believed to be justified.

2. Special efforts taken to check the alinement and rigidity of the nose and tail sections in preparing the second bomb for flight test seem to have eliminated most of the adverse aerodynamic out-of-trimm effect obtained with the first bomb. However even with this adverse out-of-trim effect, the data obtained towards the latter part of each

drop test showed that these bombs are capable of executing steady-state acceleration changes of the order of one times the acceleration due to gravity.

3. Although previously published information intimated that a cruciform configuration with flap-type ailerons would not achieve adequate automatic roll control for the type of bomb flight tested for this investigation due to the large rolling moments induced by simultaneous pitching and yawing, the over-all operation of the flicker-roll autopilot was considered to be entirely satisfactory. The steady-state roll oscillations obtained for the second bomb, however, were of smaller amplitude and slightly higher frequency due to a somewhat larger aileron deflection and shorter average time lag between gyro signal and aileron deflection. Although the roll autopilot was considered effective in maintaining small roll amplitudes, evidence to indicate that roll coupling was affecting the longitudinal and directional motions was obtained in some cases.

4. It was found necessary to add heaters to all servo components because of malfunctions obtained at altitude and during stratochamber cold checks. It is believed that serious malfunctions of the pneumatic components would have occurred during the free-flight tests if this had not been done due to the possibility of moisture condensation in the servo valves, which would have frozen when the bombs were subjected to the extreme cold conditions associated with drops from 36,000 feet.

5. High-frequency oscillations of varying intensity were superimposed on accelerometer telemeter records. It is concluded that these oscillations resemble what is normally called buffeting.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 2, 1953.

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TABLE I

DATA ON WIND VELOCITY AND DIRECTION FOR BOMBS 1 AND 2

Altitude, ft	Bomb 1		Bomb 2	
	Wind velocity, ft/sec	Wind direction, deg*	Wind velocity, ft/sec	Wind direction, deg*
2,000	19	132	9	146
4,000	39	131	17	239
6,000	77	117	20	231
8,000	87	115	37	254
10,000	94	109	28	244
12,000	144	118	12	265
14,000	194	114	11	228
16,000	206	120	11	215
18,000	222	116	11	193
20,000	218	119	16	186
22,000	218	115	20	214
24,000			30	210
26,000			29	194
28,000			36	181
30,000			38	193
32,000			40	200
34,000			47	219
36,000			50	216

*This angle is measured clockwise with respect to the horizontal range axis of the trajectory (see fig. 4) and indicates the direction from which the wind originates.

TABLE II

DATA ON ACCELEROMETER HIGH-FREQUENCY OSCILLATIONS FOR BOMB 1

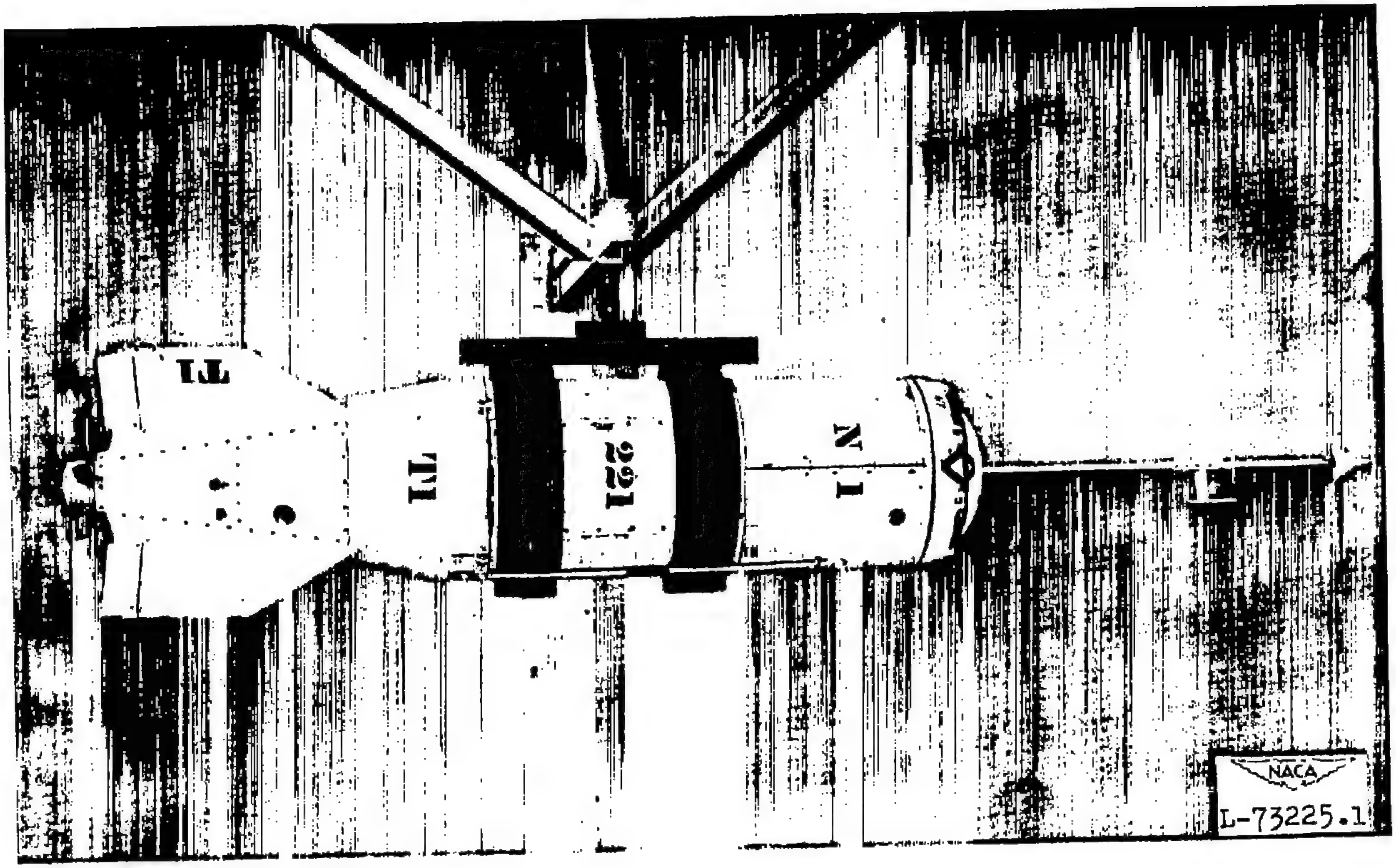
Flight time, sec	Mach number	Control-vane position	Oscillation frequency, cps	Estimated total oscillation amplitude, g
Normal acceleration				
8.8	0.58	Pitch and yaw out	100	0.29
12.0	.64	Pitch and yaw in	111	.29
17.0	.72	Pitch and yaw in	114	.47
26.4	.86	Pitch out	67	.14
36.0	.96	Pitch and yaw out	67	.28
42.9	.98	Pitch and yaw in	72	.28
47.6	.97	Pitch and yaw in	70	.28
50.7	.94	Pitch out	72	.53
57.9	.83	Pitch and yaw out	67	.45
59.9	.80	Pitch and yaw out	72	.62
Transverse acceleration				
5.0	0.55	Pitch and yaw out	100	0.50
12.3	.64	Pitch and yaw in	113	.69
18.1	.74	Pitch out	133	1.18
27.2	.87	Pitch out	120	1.07
32.8	.93	Pitch and yaw out	70	.48
41.5	.98	Pitch and yaw in	150	3.15
47.6	.97	Pitch and yaw in	150	1.98
49.2	.96	Pitch out	75	.93
58.9	.81	Pitch and yaw out	71	.97
Longitudinal acceleration				
5.0	0.56	Pitch and yaw out	100	0.53
13.0	.64	Pitch and yaw in	117	.10
17.1	.73	Pitch and yaw in	111	.09
25.8	.85	Pitch out	100	.06
38.7	.98	Pitch and yaw out	150	.24
43.2	.99	Pitch and yaw in	150	.16
47.6	.97	Pitch and yaw in	157	.33
50.2	.95	Pitch out	160	.47
55.8	.84	Pitch out	140	.31
58.3	.82	Pitch and yaw out	150	.26

TABLE III

DATA ON TRANSVERSE ACCELEROMETER HIGH-FREQUENCY

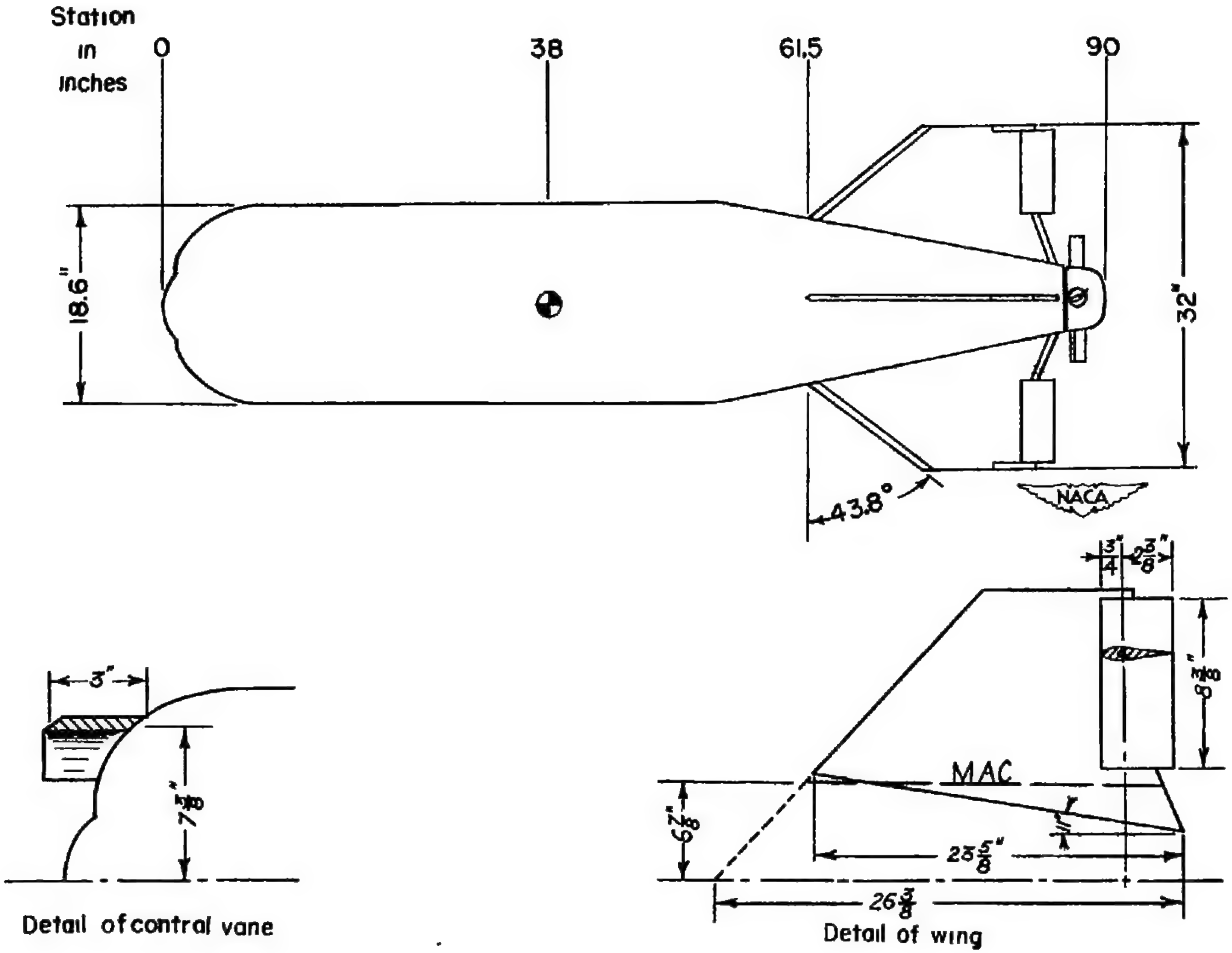
OSCILLATIONS FOR BOMB 2

Flight time, sec	Mach number	Control-vane position	Oscillation frequency, cps	Total oscillation amplitude, g
5.9	0.53	Pitch and yaw out	65	0.34
7.8	.54	Yaw out	100	.65
11.8	.59	Pitch and yaw in	100	.52
21.9	.77	Pitch and yaw out	100	.69
22.2	.77	Yaw out	133	1.14
26.5	.84	Yaw out	70	.56
27.0	.85	Pitch and yaw in	145	1.22
31.9	.90	Pitch and yaw out	133	.75
36.6	.91	Pitch and yaw out	71	1.86
40.7	.92	Yaw out	67	1.12
41.3	.92	Pitch and yaw in	150	1.38
45.0	.92	Pitch and yaw in	70	.68
45.9	.92	Pitch and yaw out	67	1.99
51.4	.88	Yaw out	154	1.40
54.7	.85	Yaw out	67	1.51



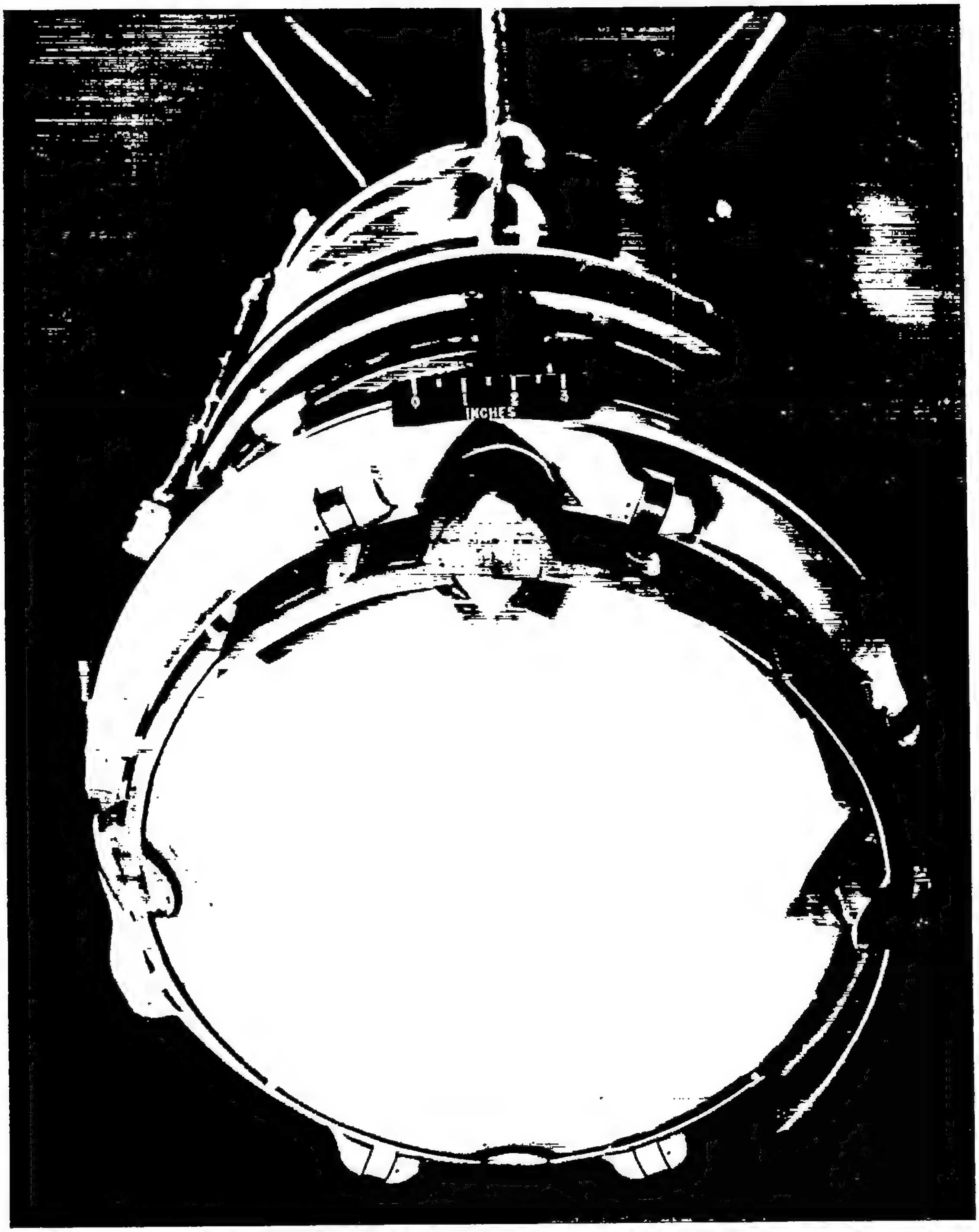
(a) Photograph of bomb.

Figure 1.- Photographs and sketch of one of the bombs used in the free-flight drop tests.



(b) Sketch of bomb.

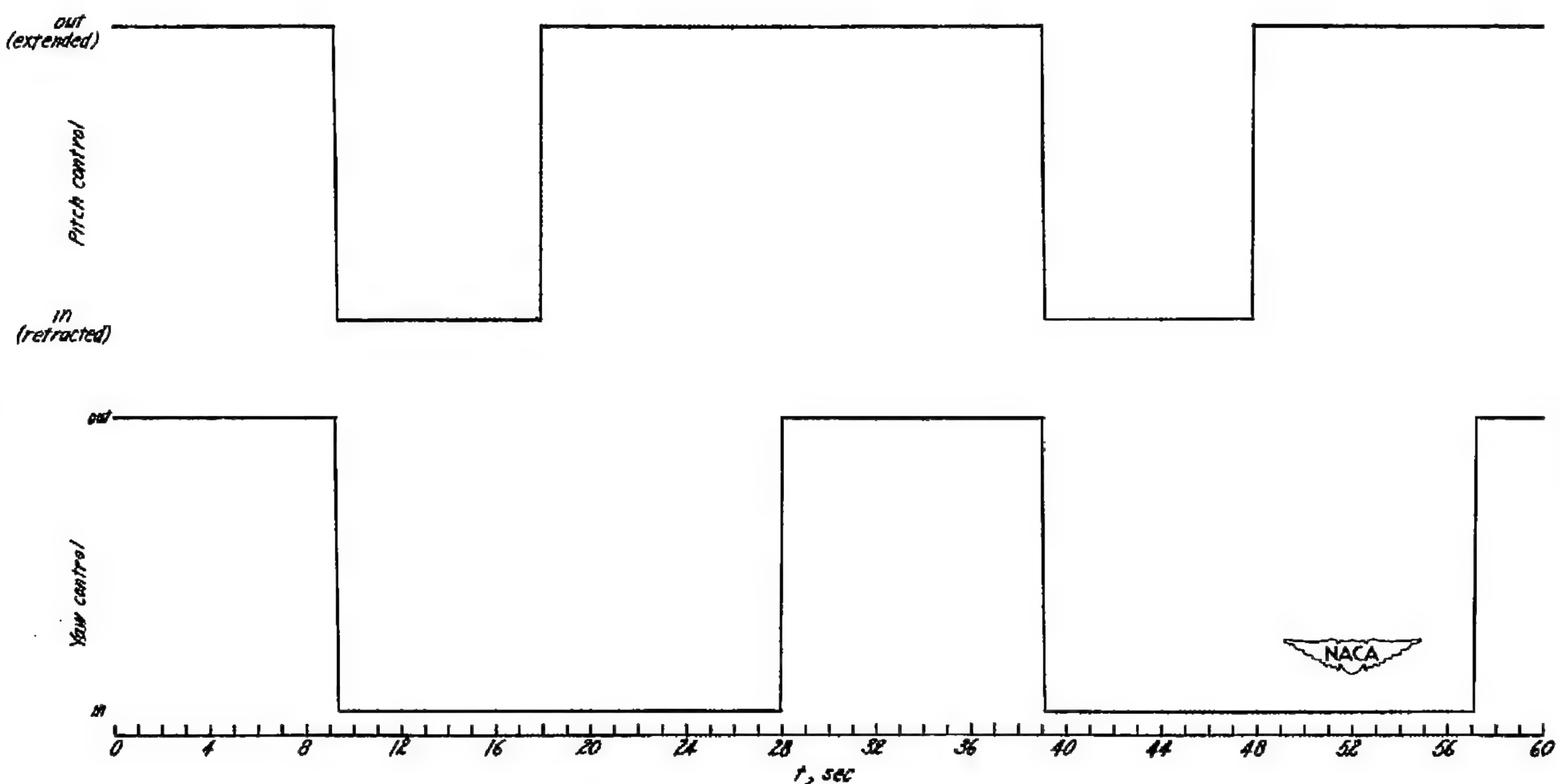
Figure 1.- Continued.



L-68949.2

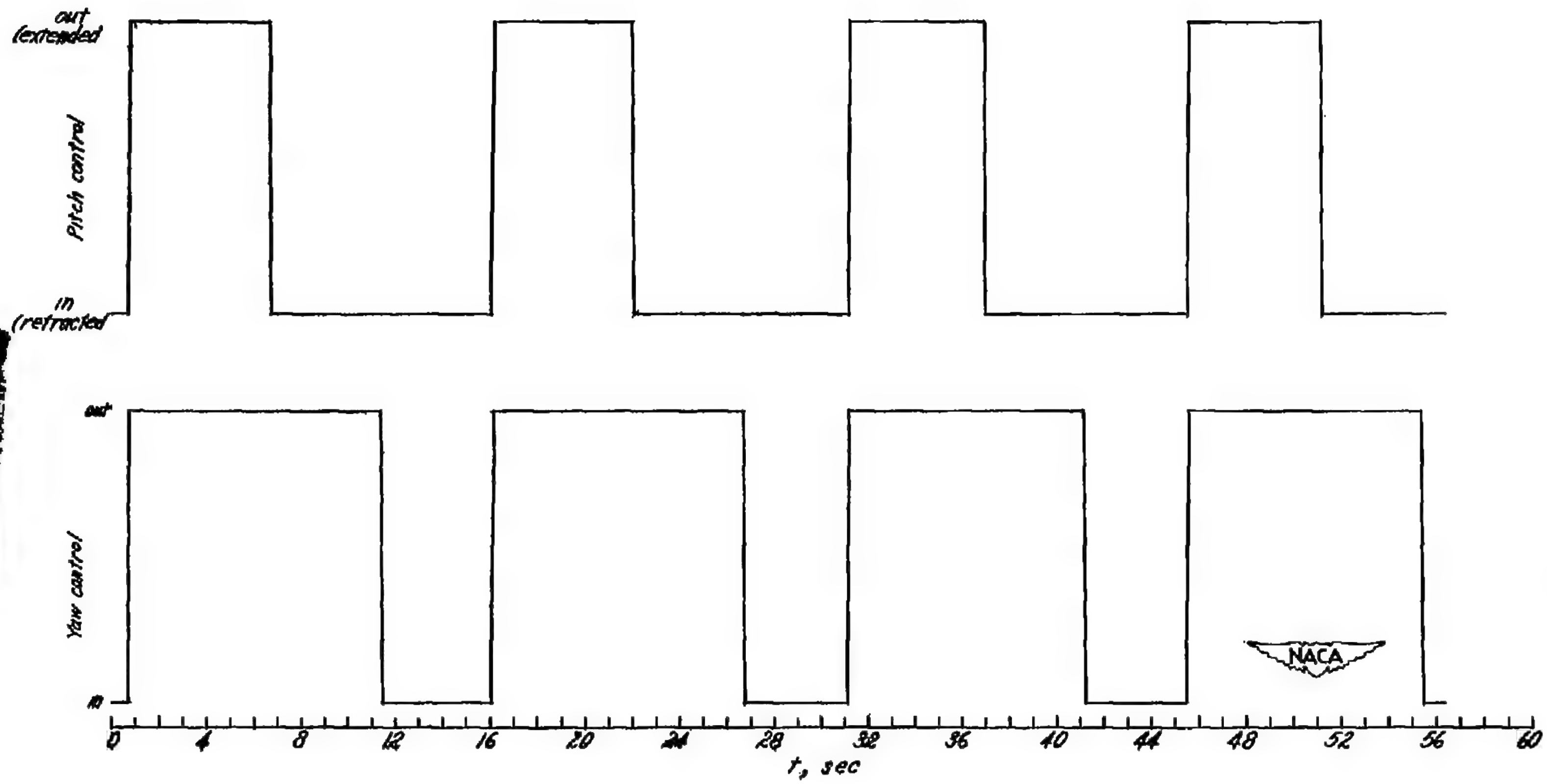
(c) Photograph of bomb nose with pitch and yaw control vanes extended.

Figure 1.- Concluded.



(a) Bomb 1.

Figure 2.- Pulsing sequences of pitch and yaw control vanes used in the free-flight drop tests.



(b) Bomb 2.

Figure 2.- Concluded.

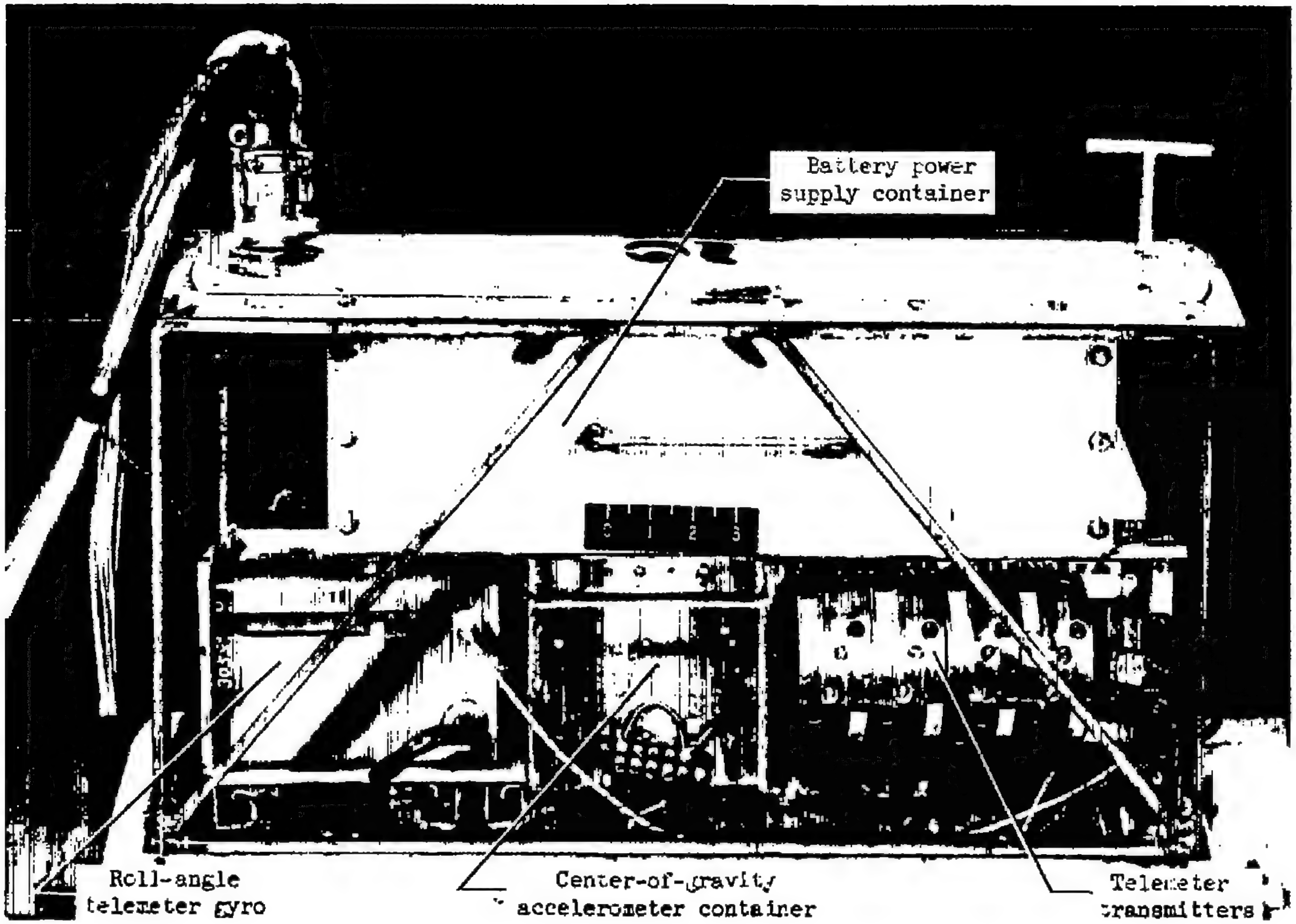


Figure 3.- Photograph of bomb hatch showing locations of principal components of telemeter instrumentation.

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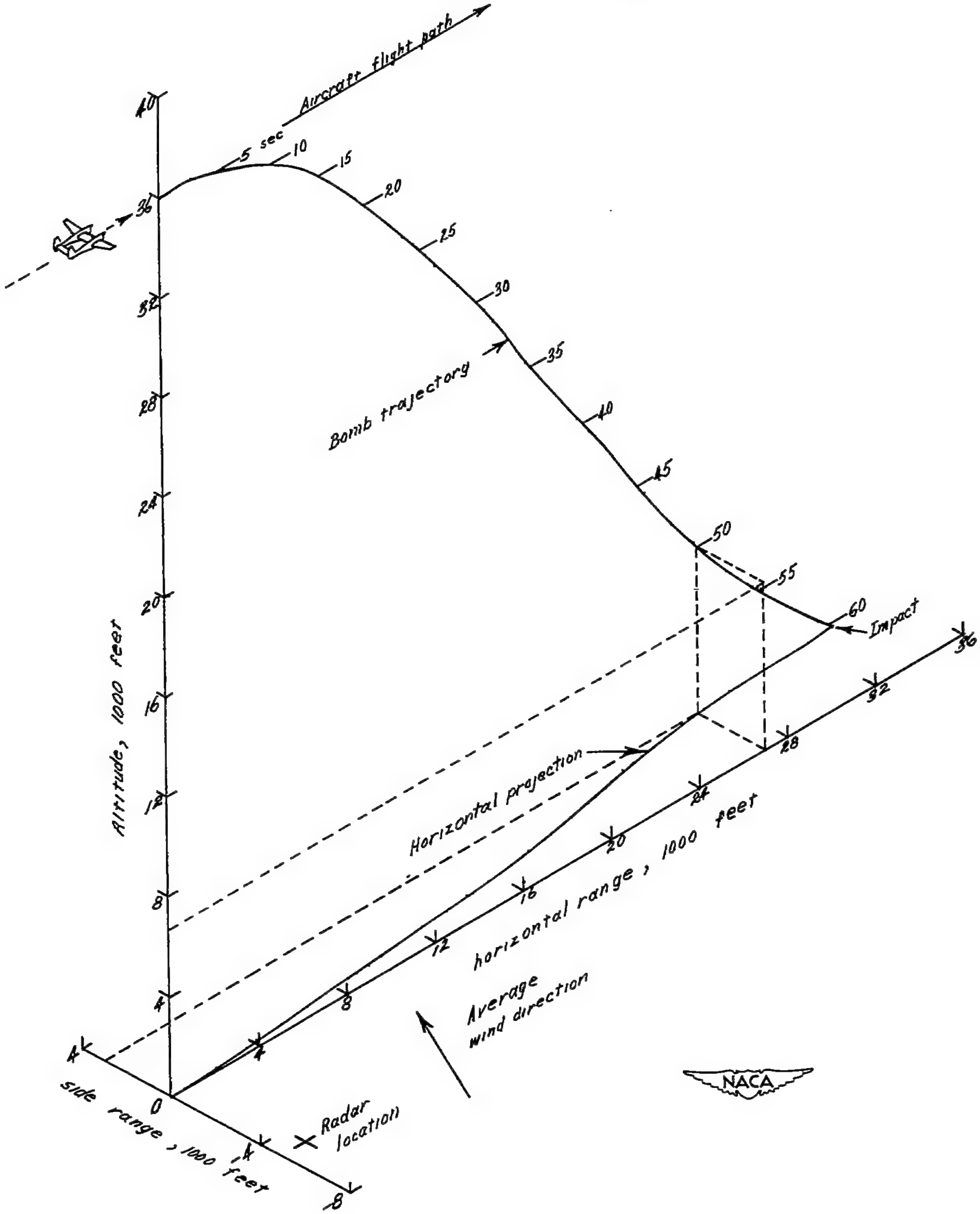
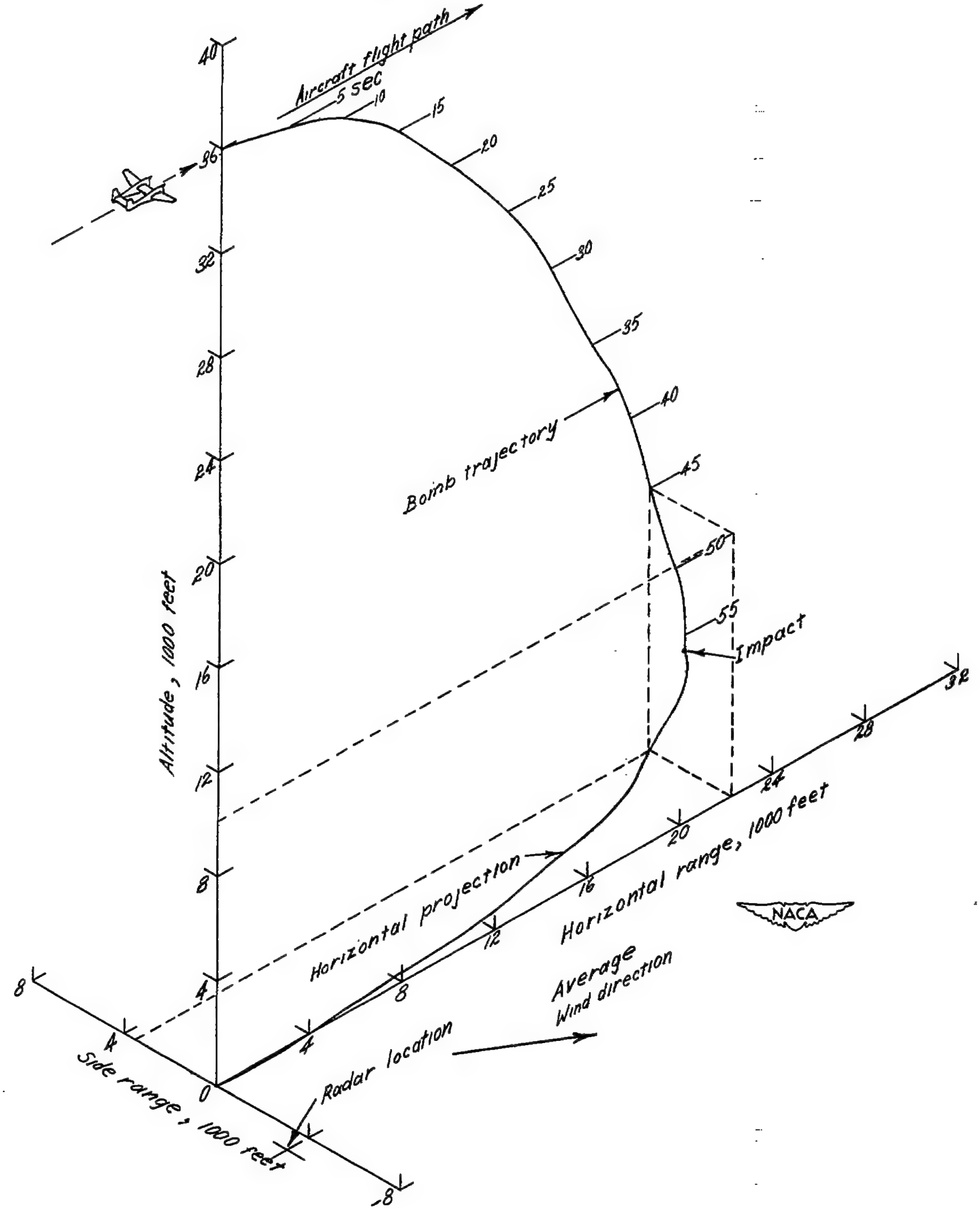
L-73270.1



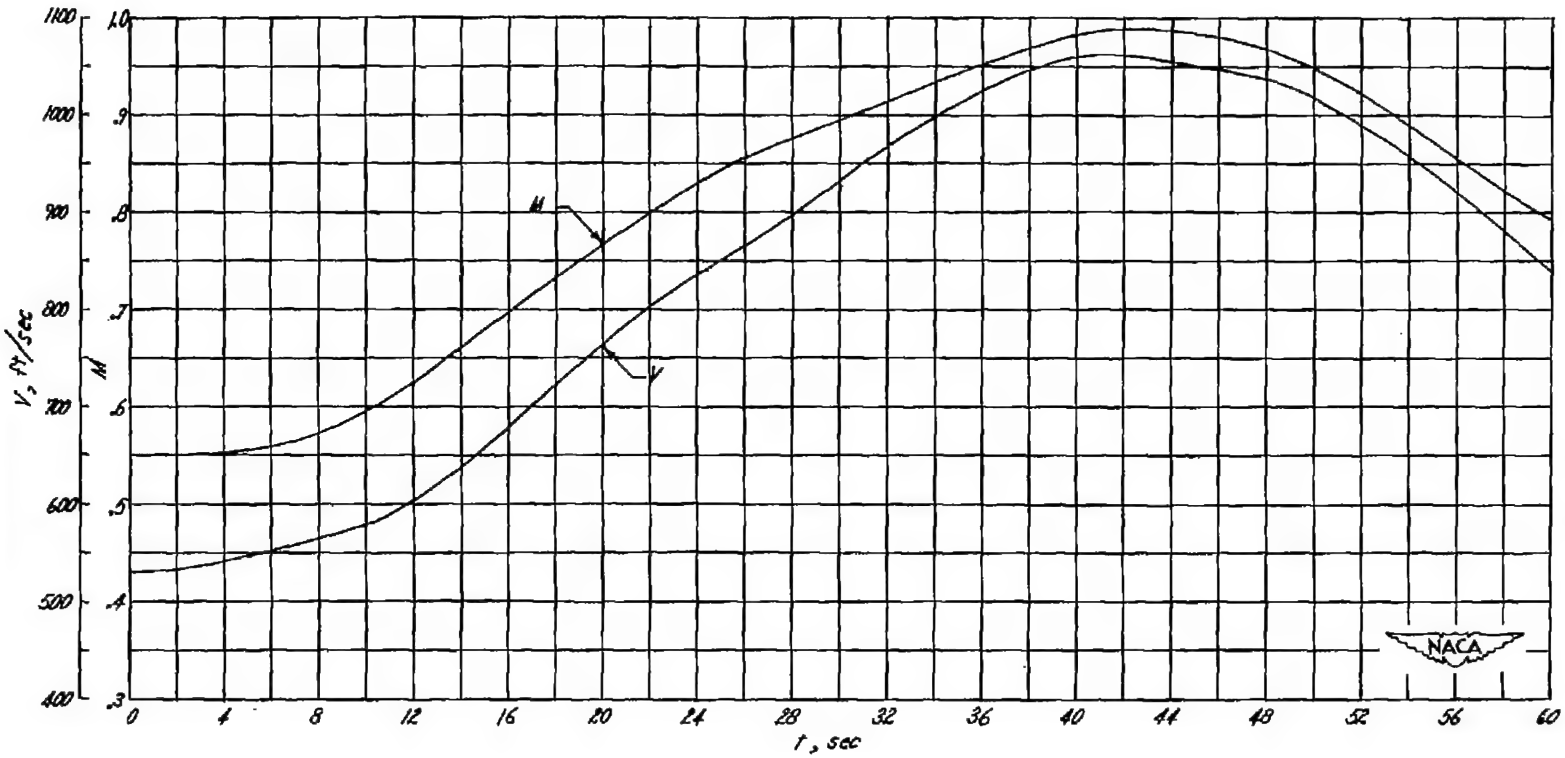
(a) Bomb 1.

Figure 4.- Trajectories of free-flight drop-test bombs obtained from ground-radar tracking data.



(b) Bomb 2.

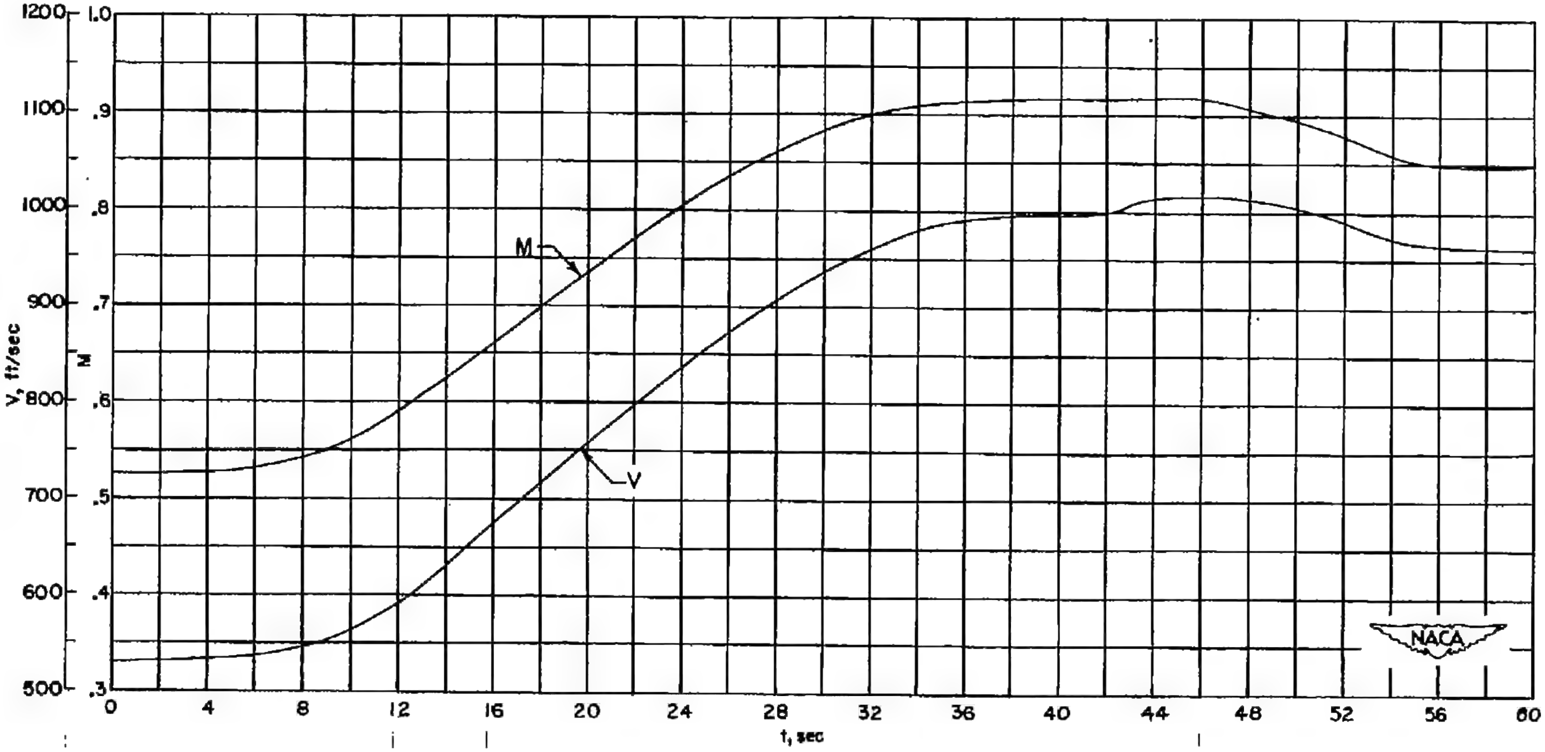
Figure 4.- Concluded.



(a) Bomb 1.

Figure 5.- Variation of Mach number and velocity with time for the free-flight drop tests.

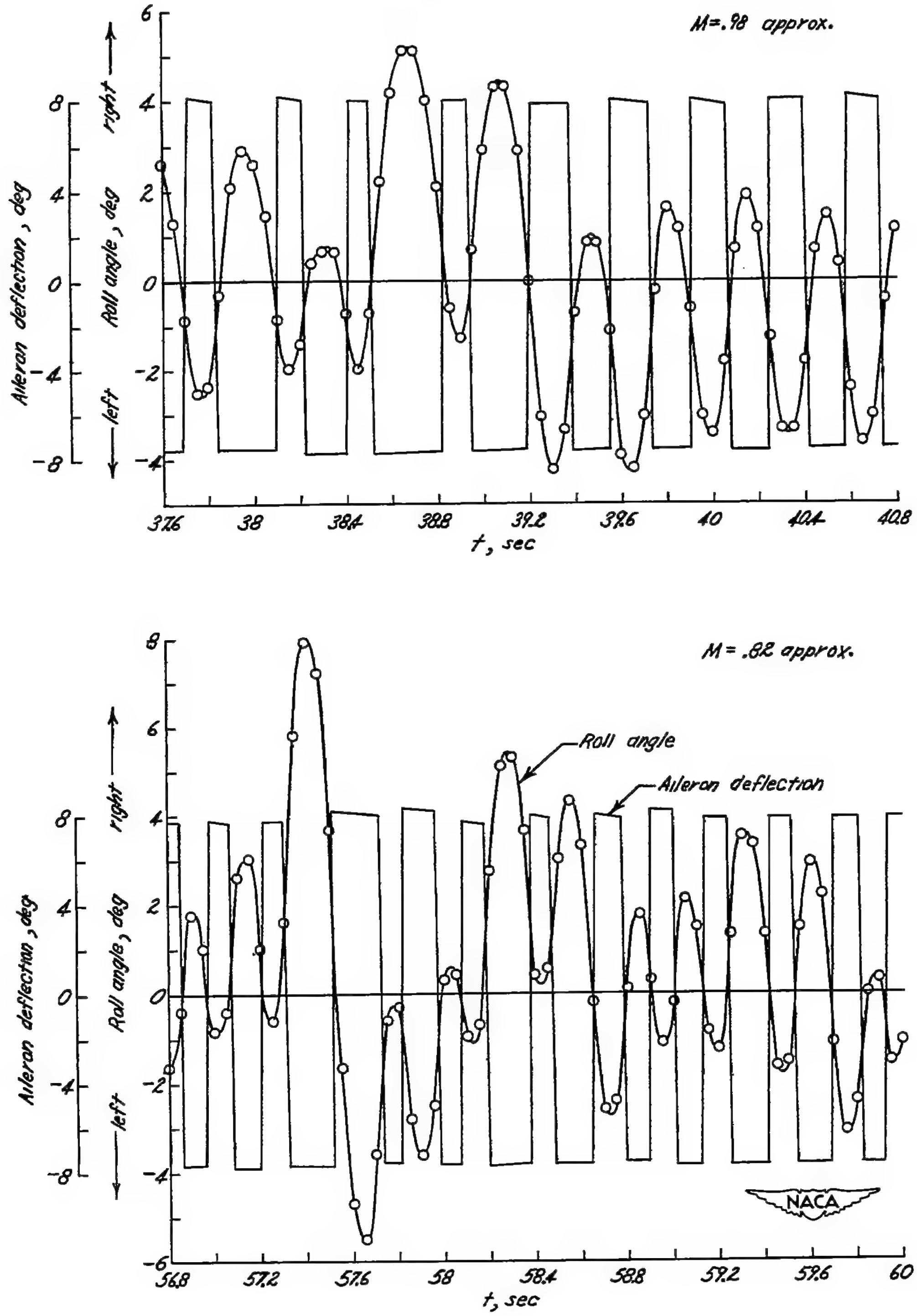
[redacted]



(b) Bomb 2.

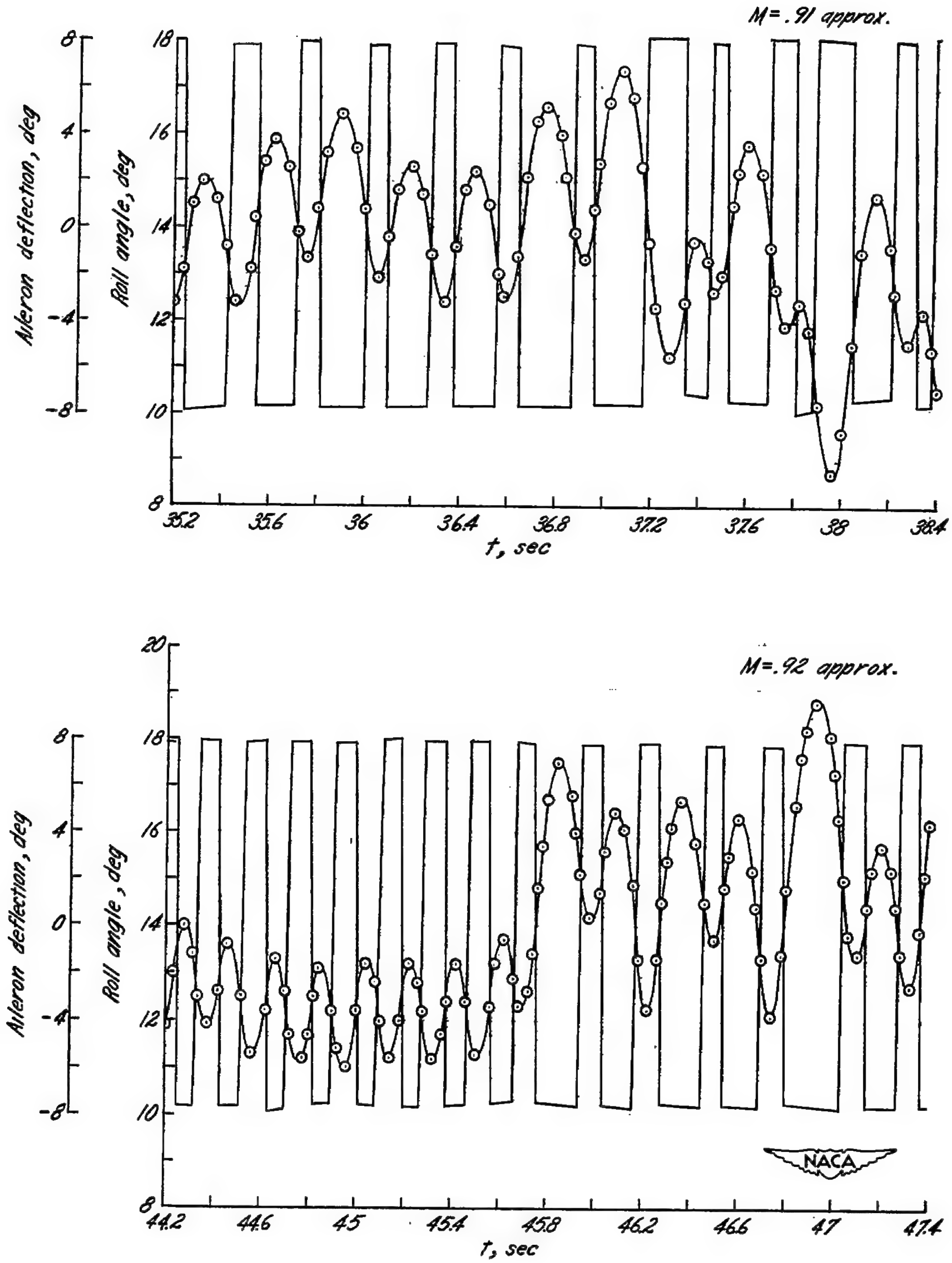
Figure 5.- Concluded.

[redacted]



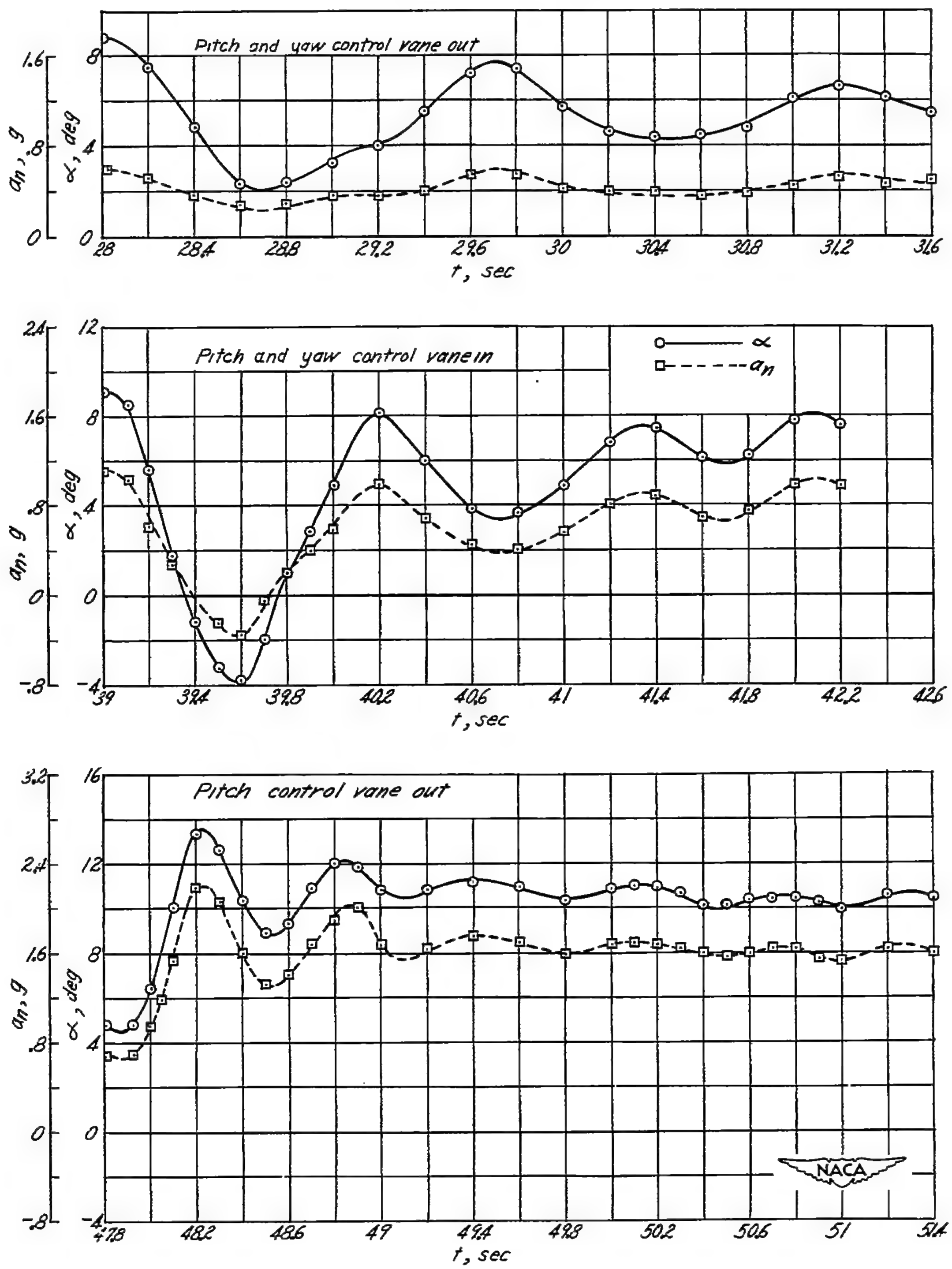
(a) Bomb 1.

Figure 6.- Portions of roll-angle and aileron-deflection data.



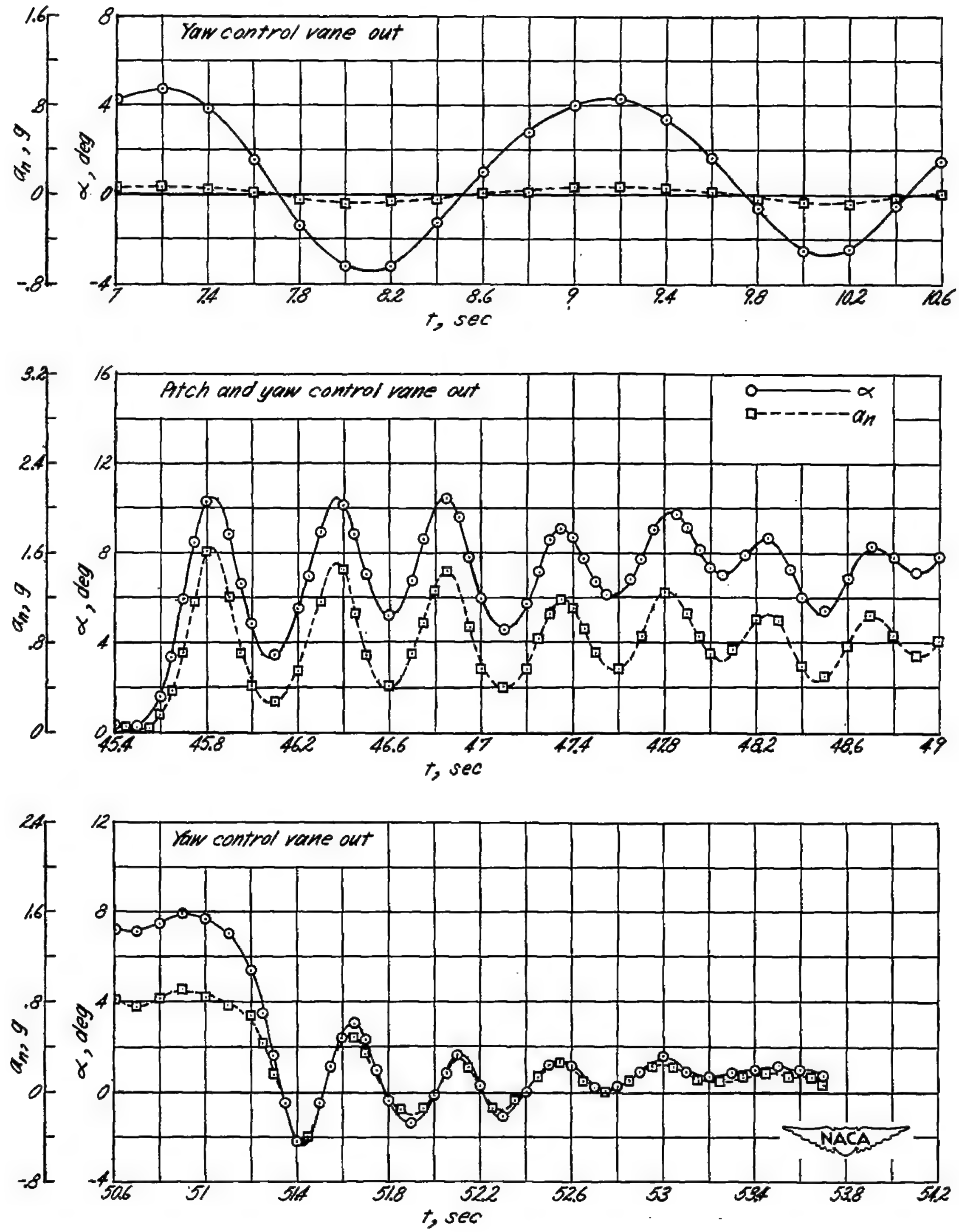
(b) Bomb 2.

Figure 6.- Concluded.



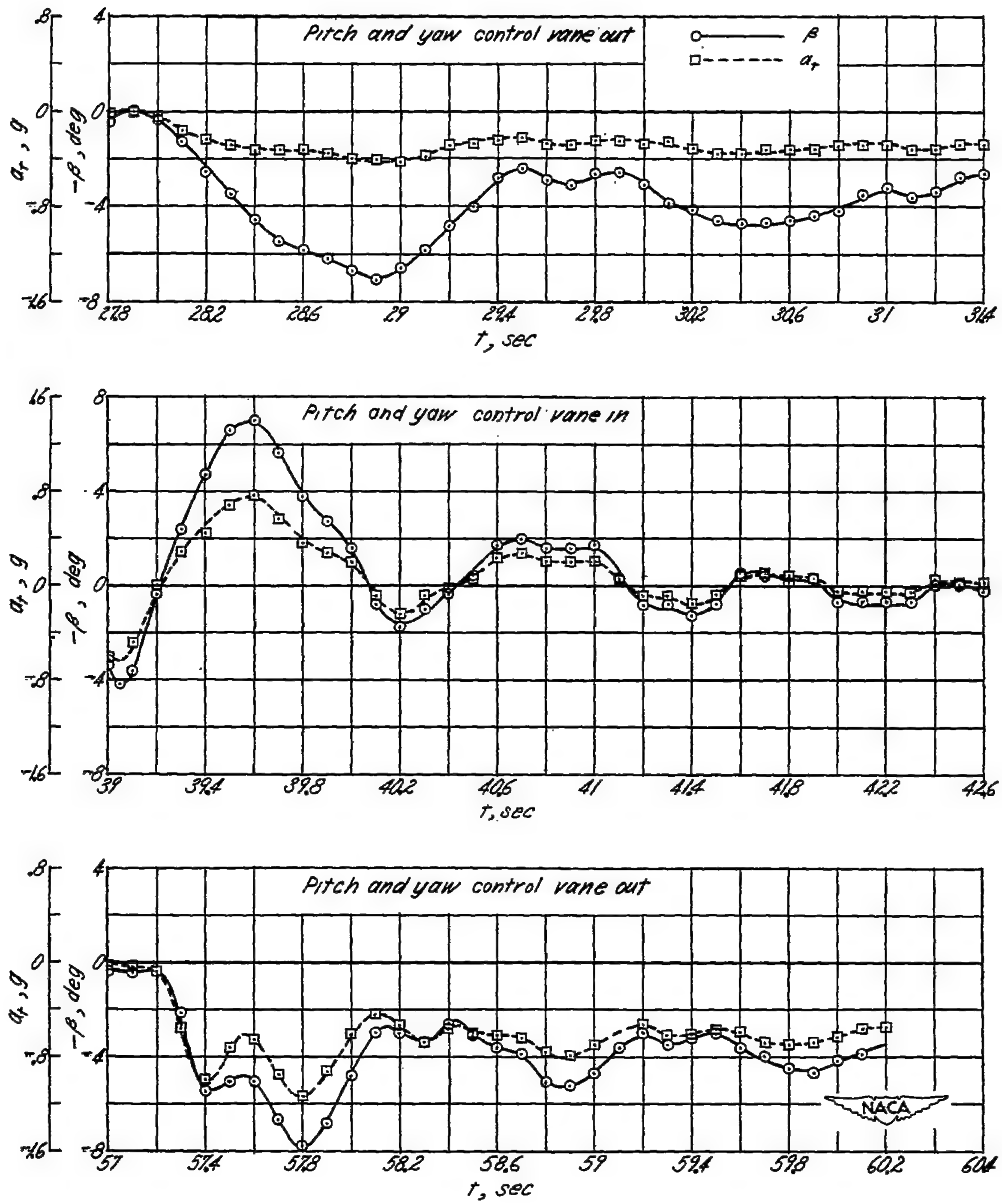
(a) Bomb 1, α and a_n.

Figure 7.- Portions of α, β, a_n, and a_t data showing transient oscillations for various pulsing conditions.



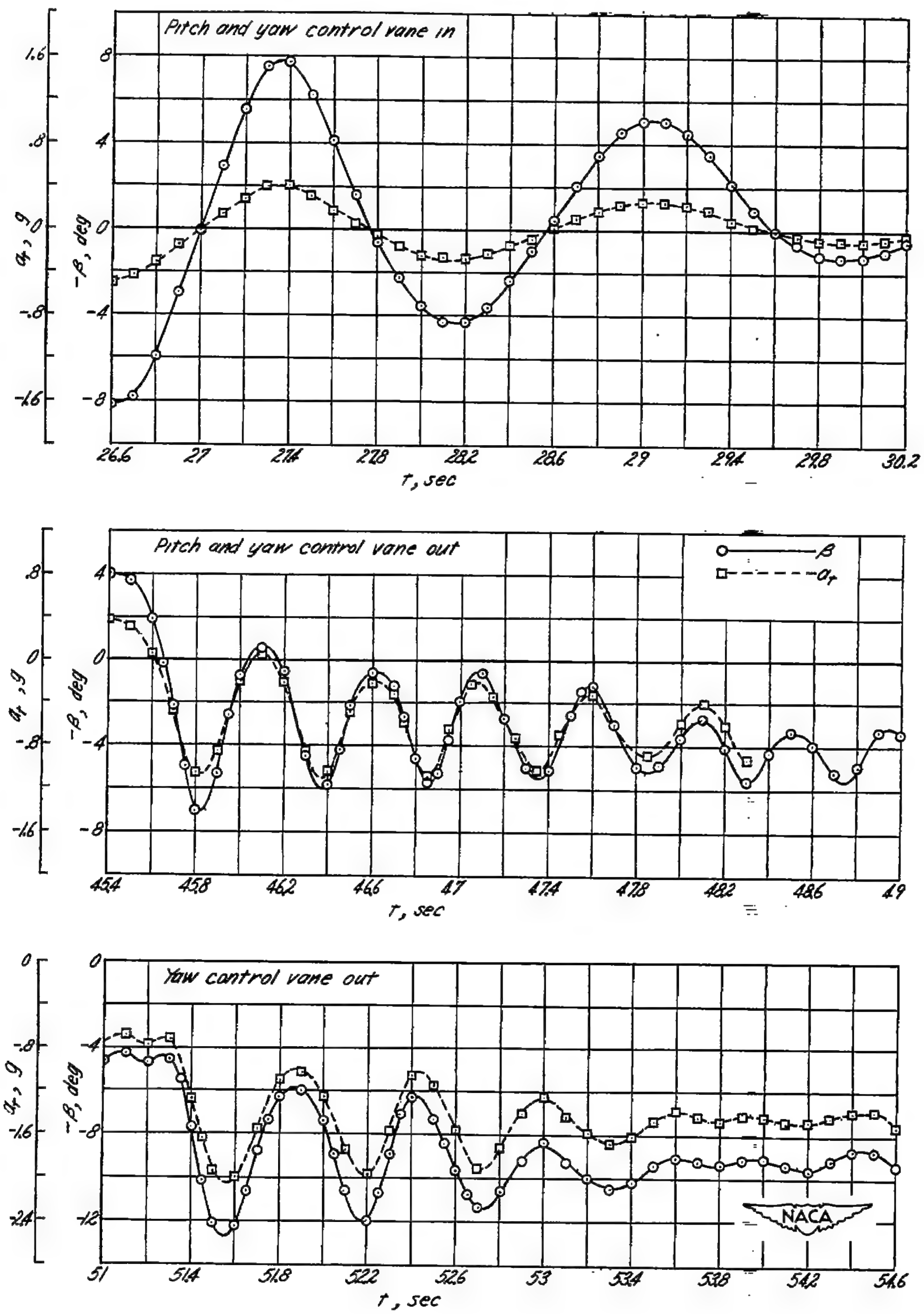
(b) Bomb 2, α and a_n.

Figure 7.- Continued.



(c) Bomb 1, β and a_t.

Figure 7.- Continued.



(d) Bomb 2, β and a_t.

Figure 7.- Concluded.

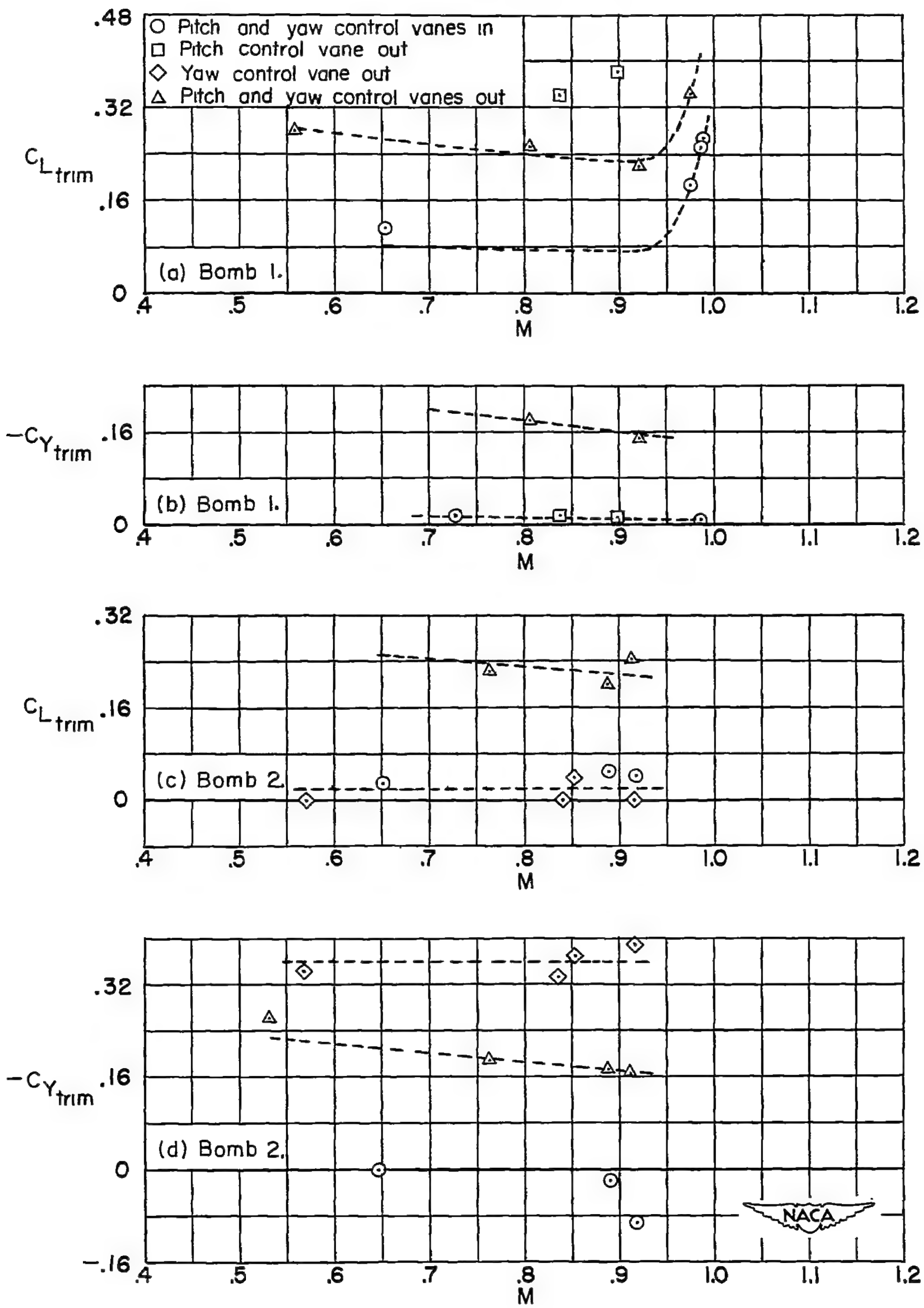


Figure 8.- Variation of flight-test trim lift and side-force coefficients with Mach number for bomb 1 and bomb 2.

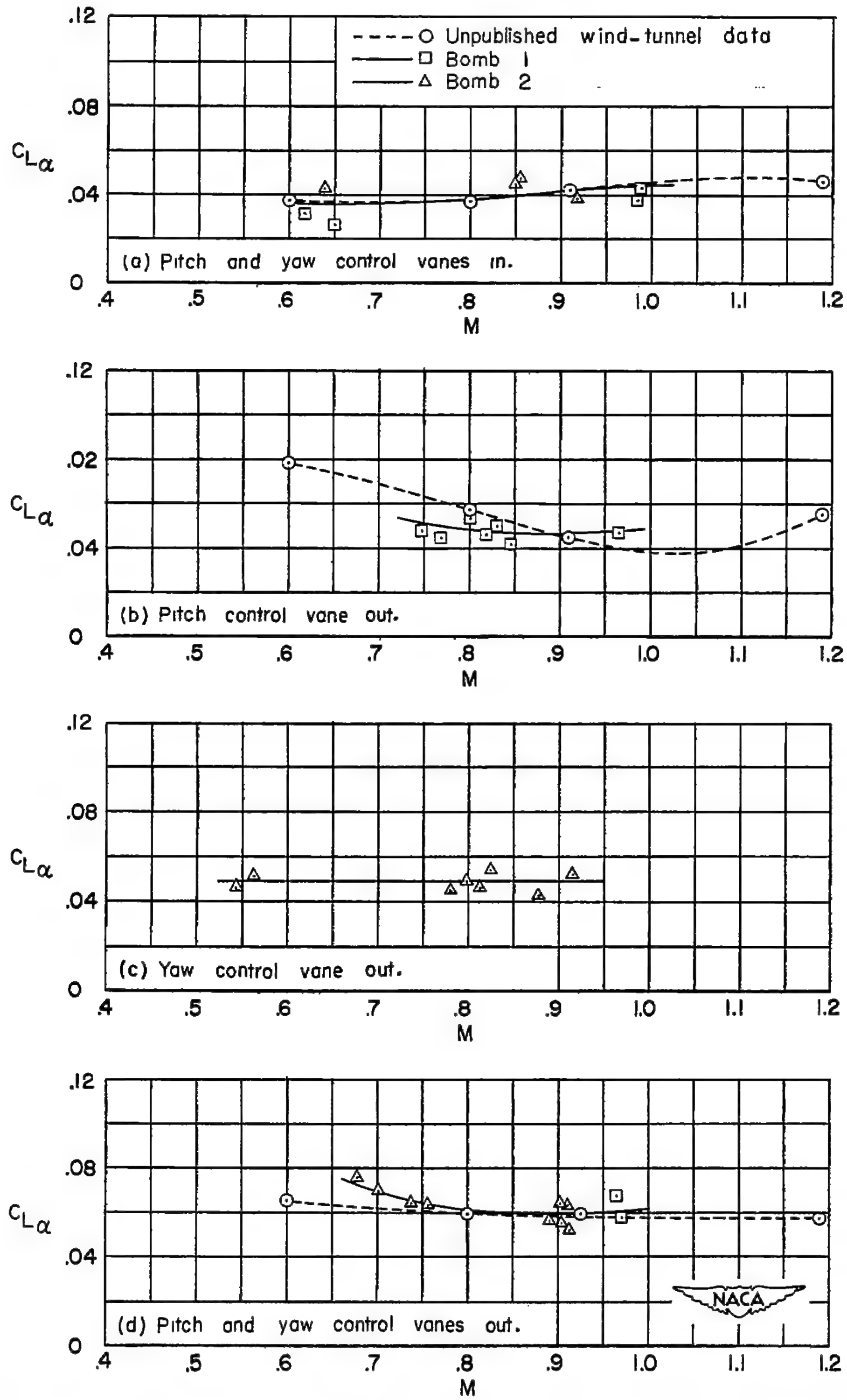
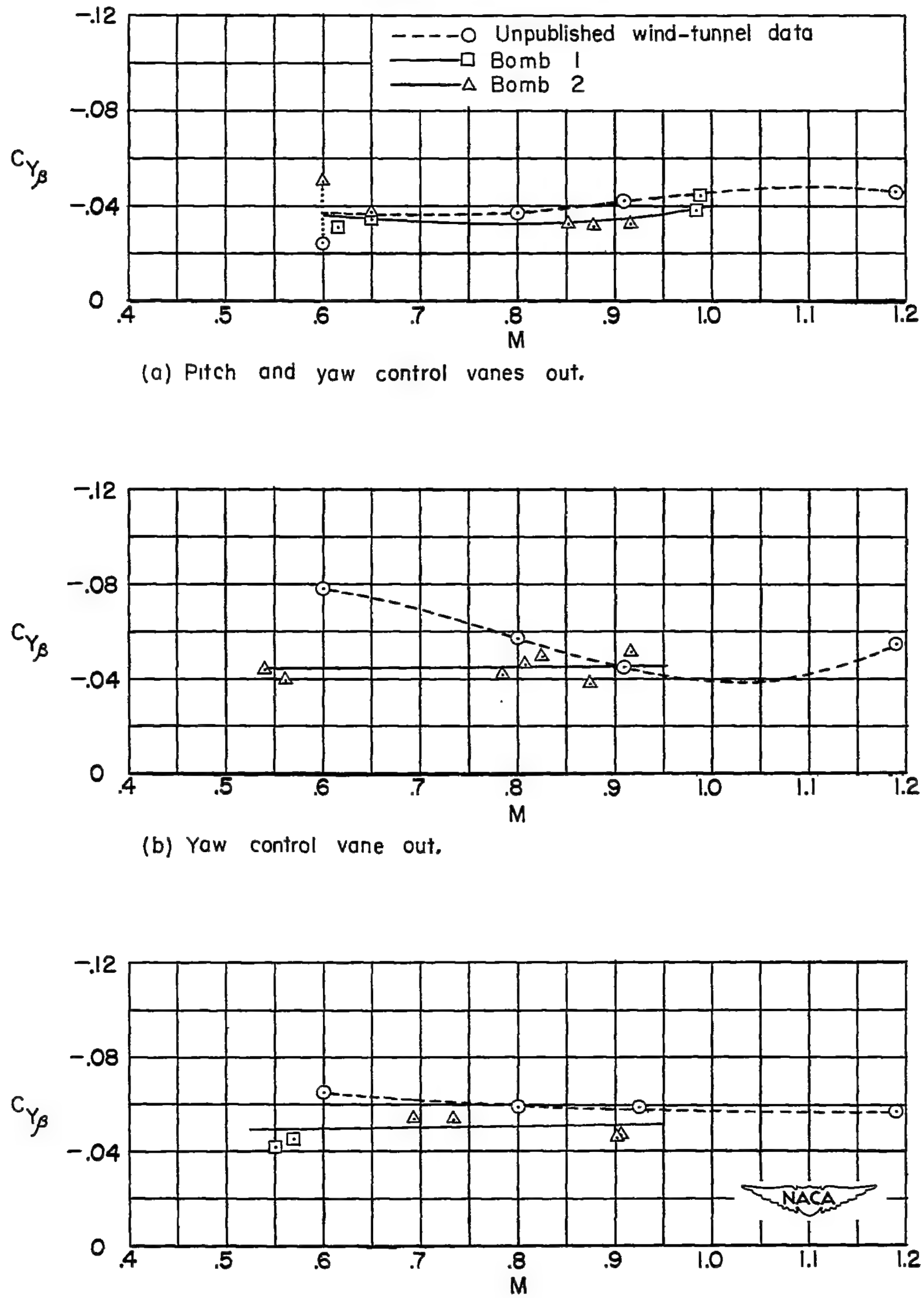


Figure 9.- Comparison of wind-tunnel and flight-test variation of lift-curve slope with Mach number for various pulsing conditions.



(a) Pitch and yaw control vanes out.

(b) Yaw control vane out.

(c) Pitch and yaw control vanes out.

Figure 10.- Comparison of wind-tunnel and flight-test variation of side-force-curve slope with Mach number for various pulsing conditions.

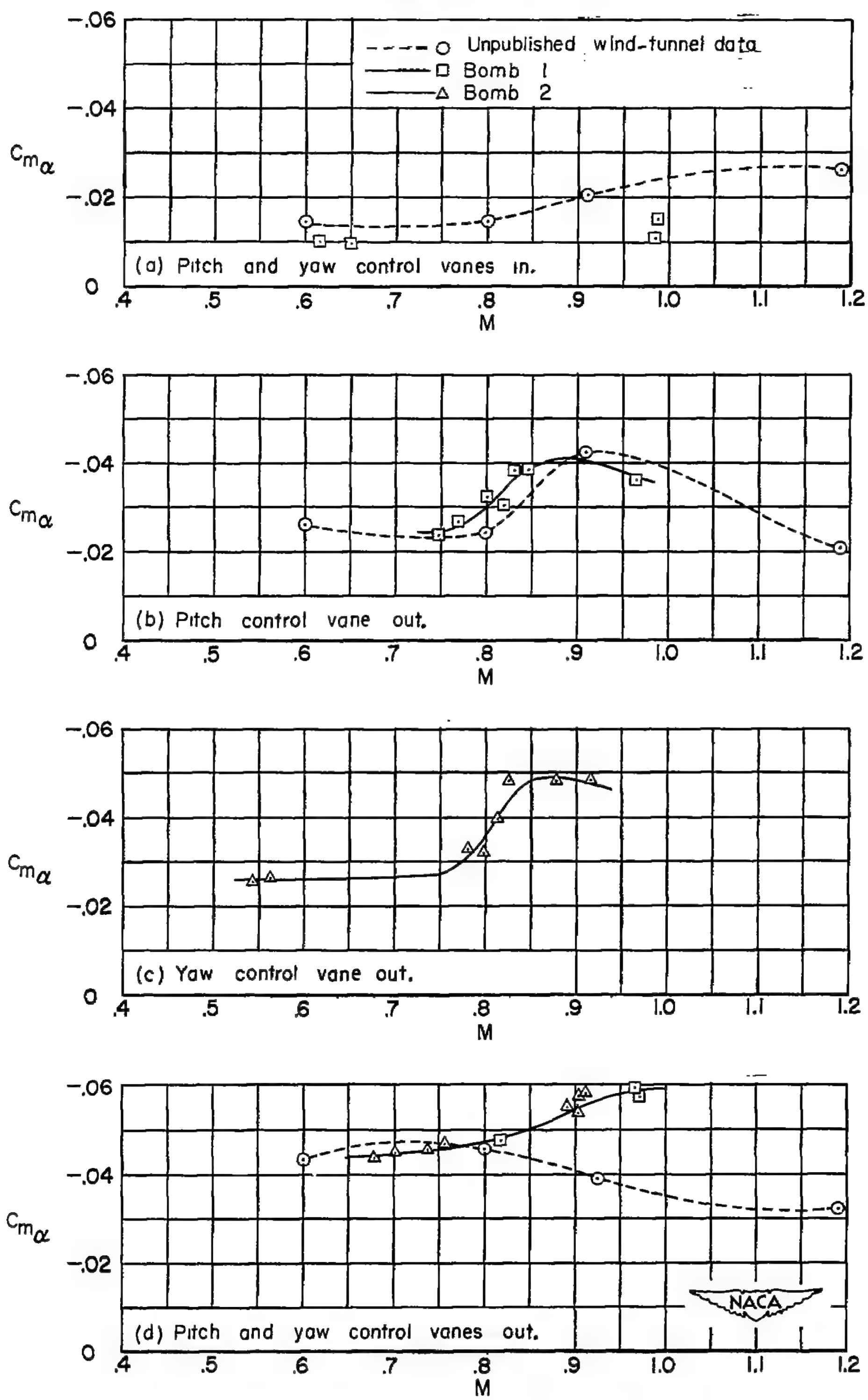


Figure 11.- Comparison of wind-tunnel and flight-test variation of static pitching-moment derivative with Mach number for various pulsing conditions.

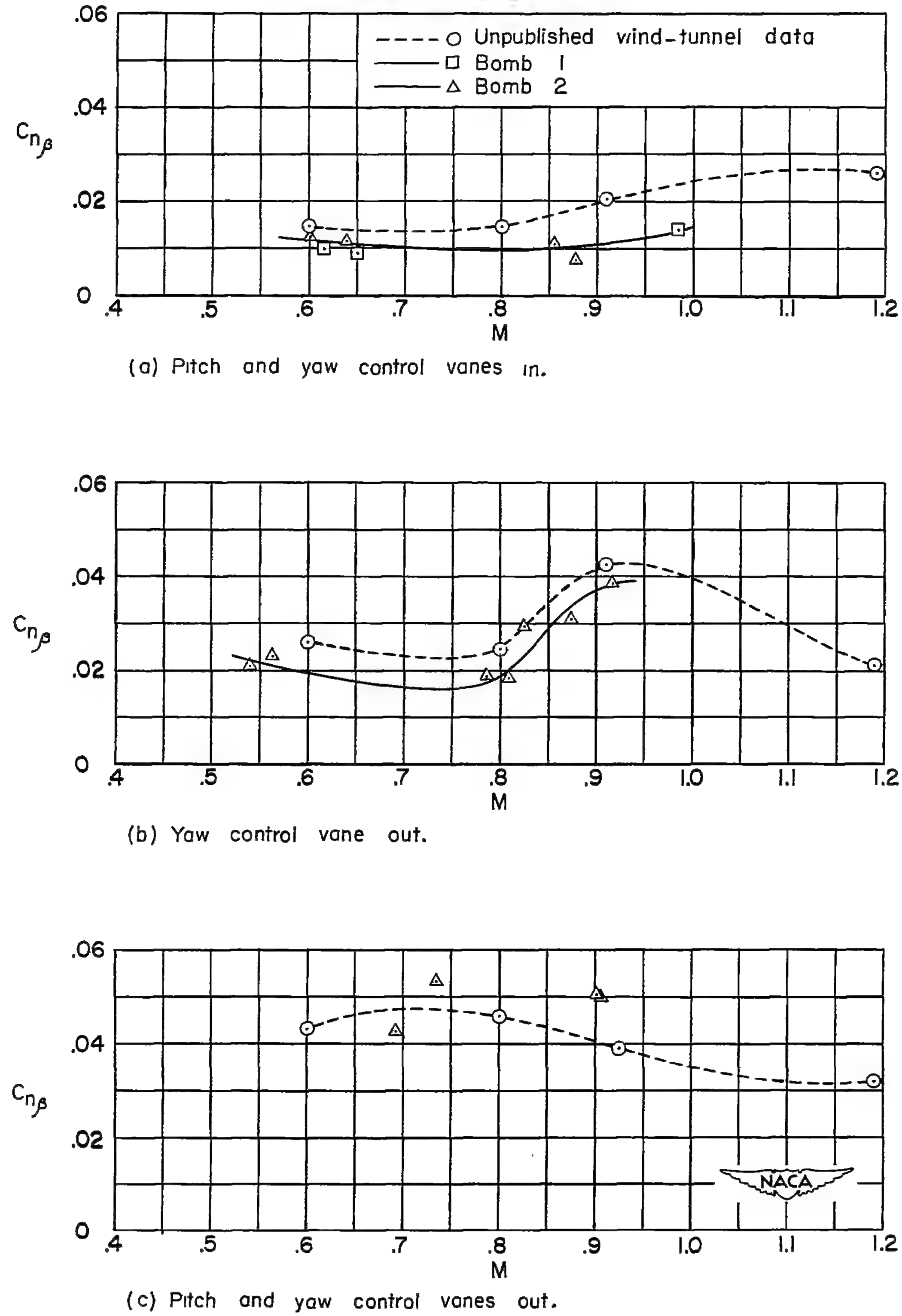


Figure 12.- Comparison of wind-tunnel and flight-test variation of static yawing-moment derivative with Mach number for various pulsing conditions.

[redacted]

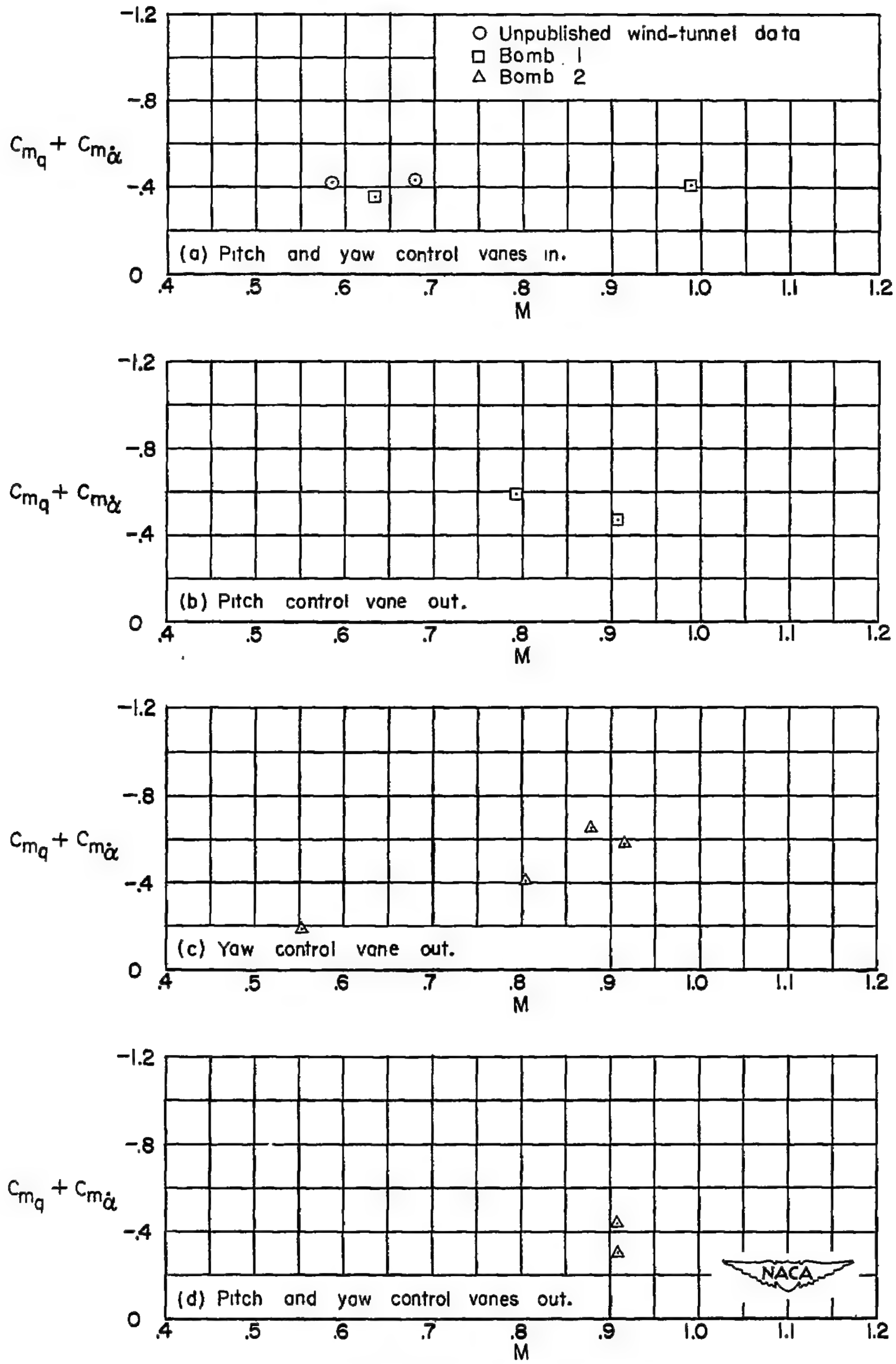
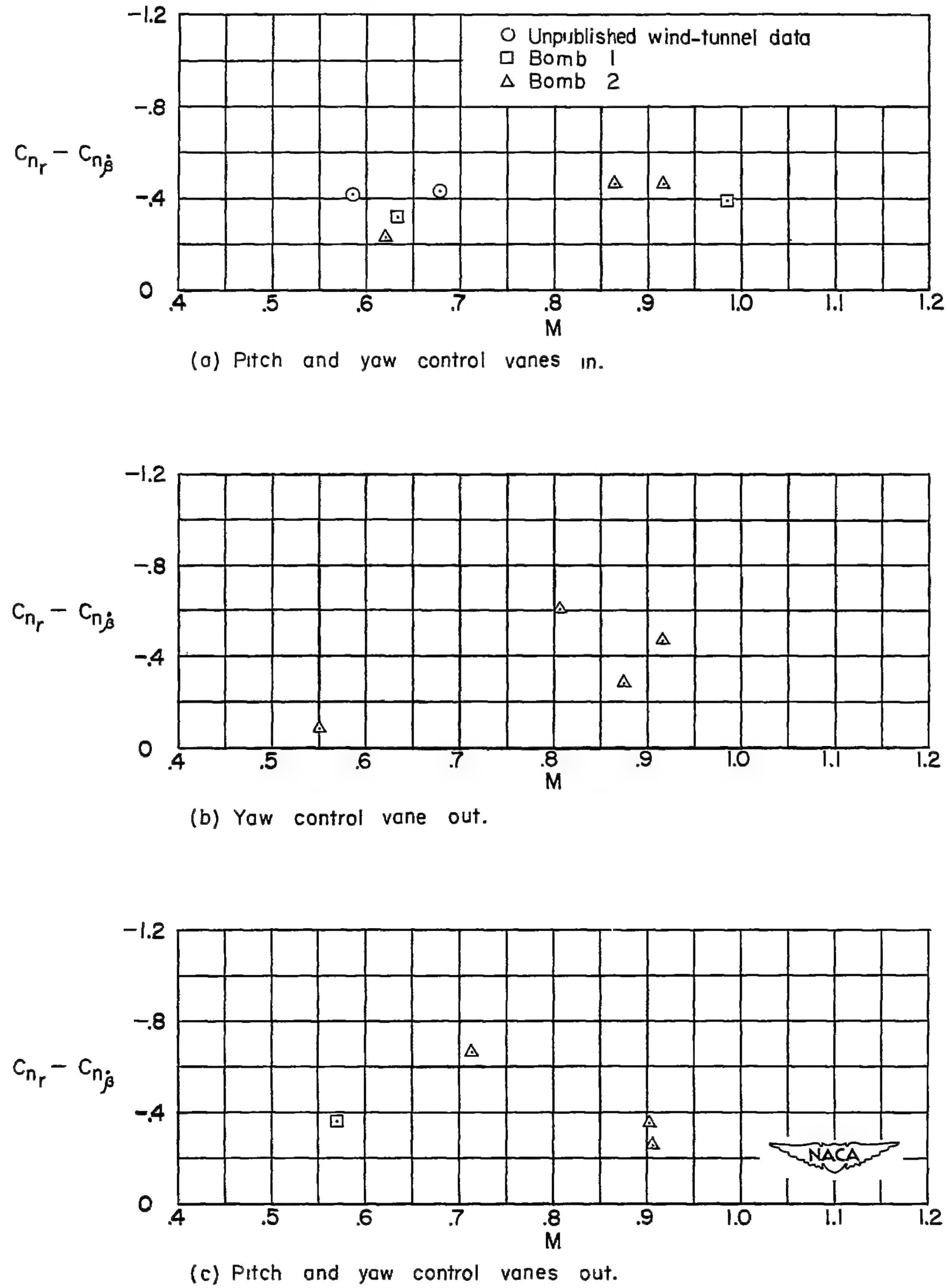


Figure 13.- Variation of aerodynamic damping-in-pitch derivative with Mach number for various pulsing conditions.

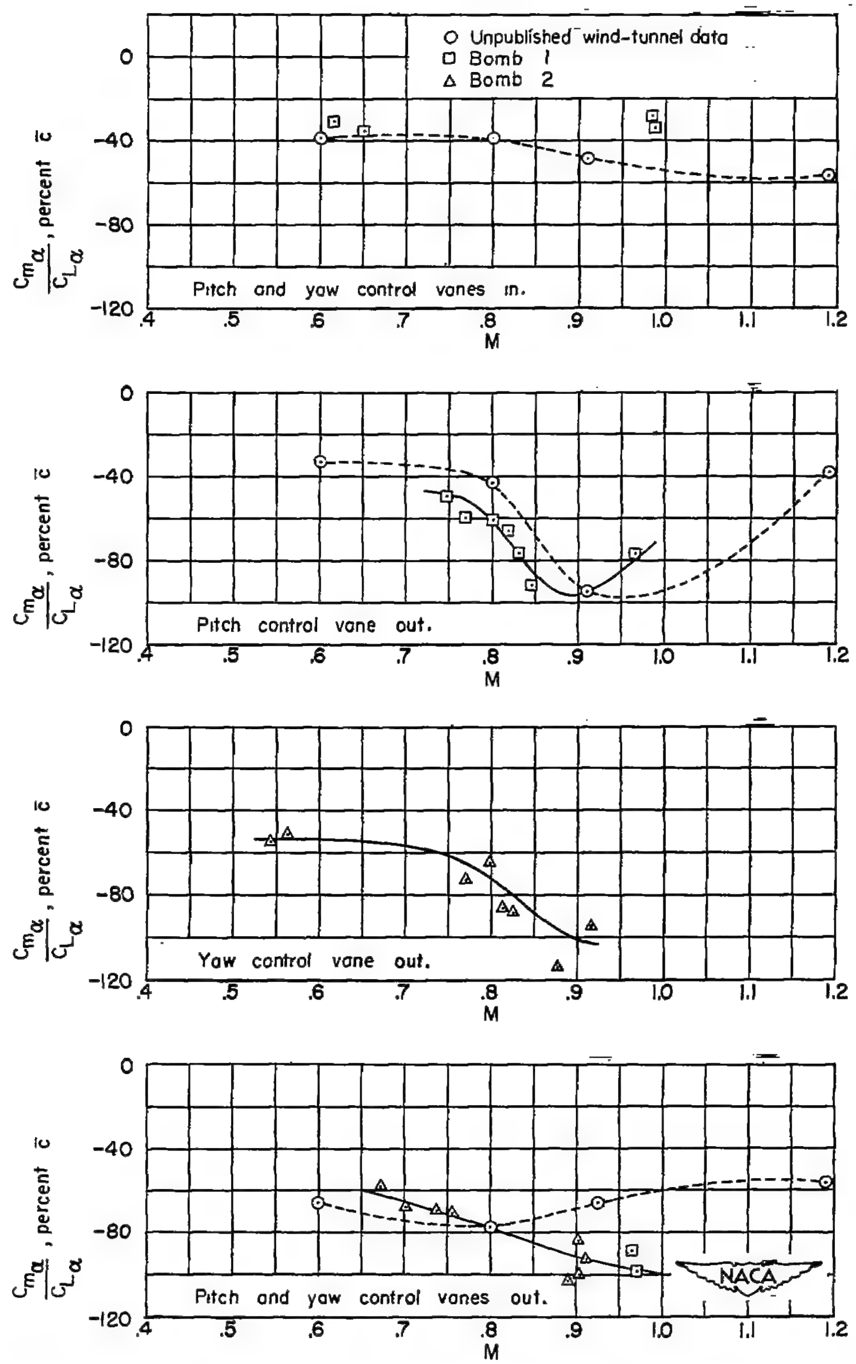


(a) Pitch and yaw control vanes in.

(b) Yaw control vane out.

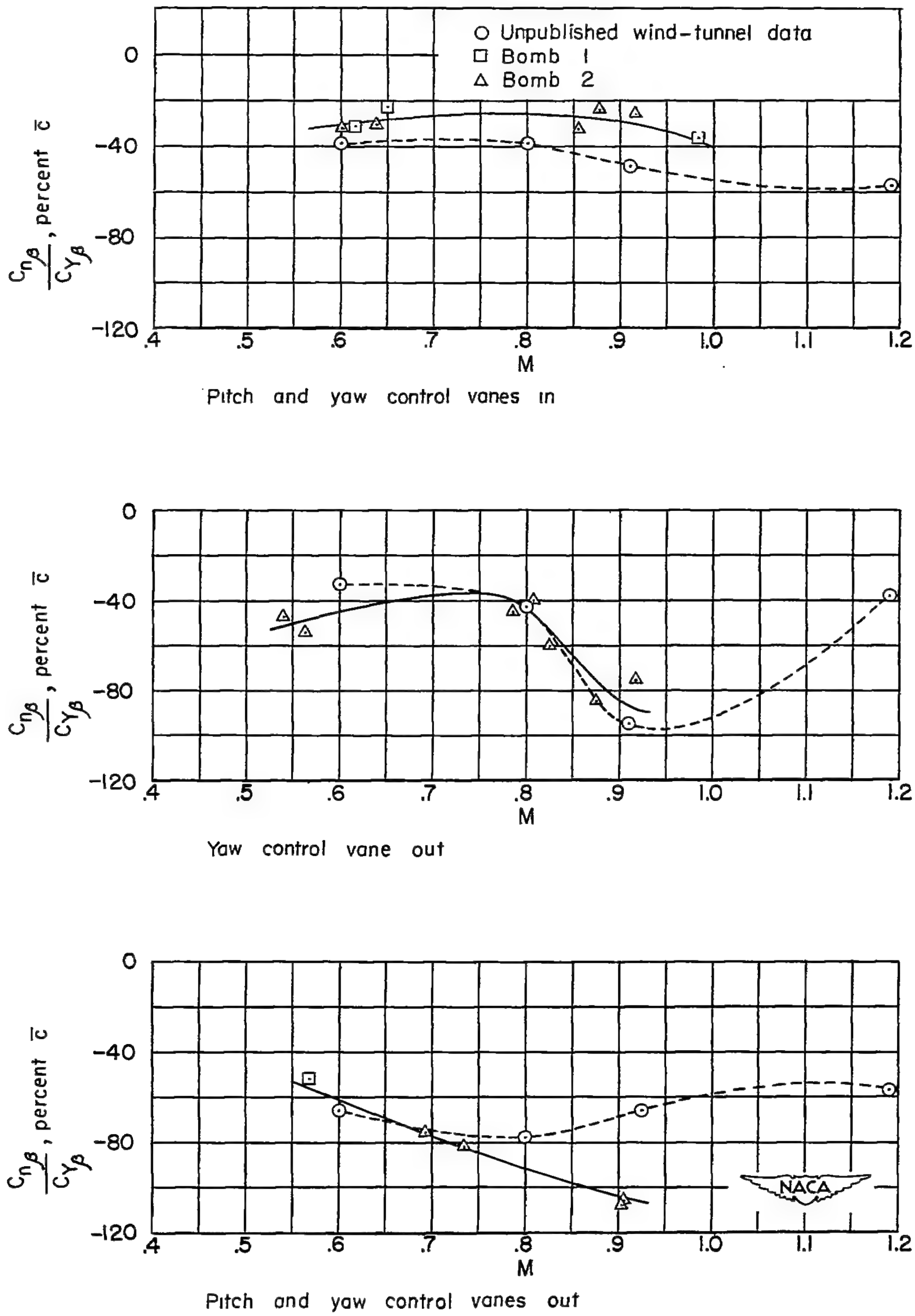
(c) Pitch and yaw control vanes out.

Figure 14.- Variation of aerodynamic damping-in-yaw derivative with Mach number for various pulsing conditions.



(a) Pitch aerodynamic-center variation with respect to center of gravity.

Figure 15.- Comparison of wind-tunnel and flight-test variation of aerodynamic-center position with Mach number for various pulsing conditions.



(b) Yaw aerodynamic-center variation with respect to center of gravity.

Figure 15.- Concluded.

[redacted]

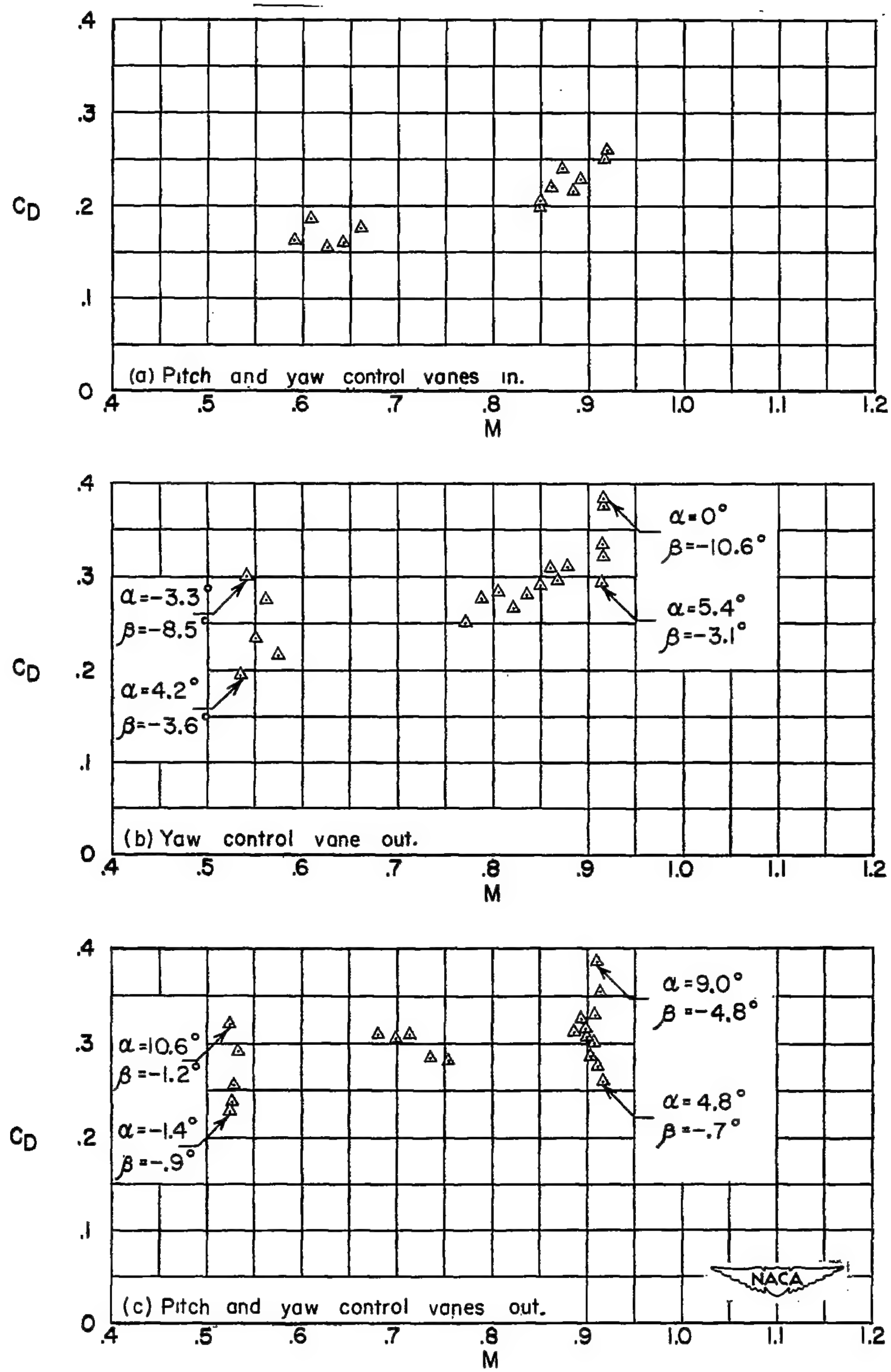
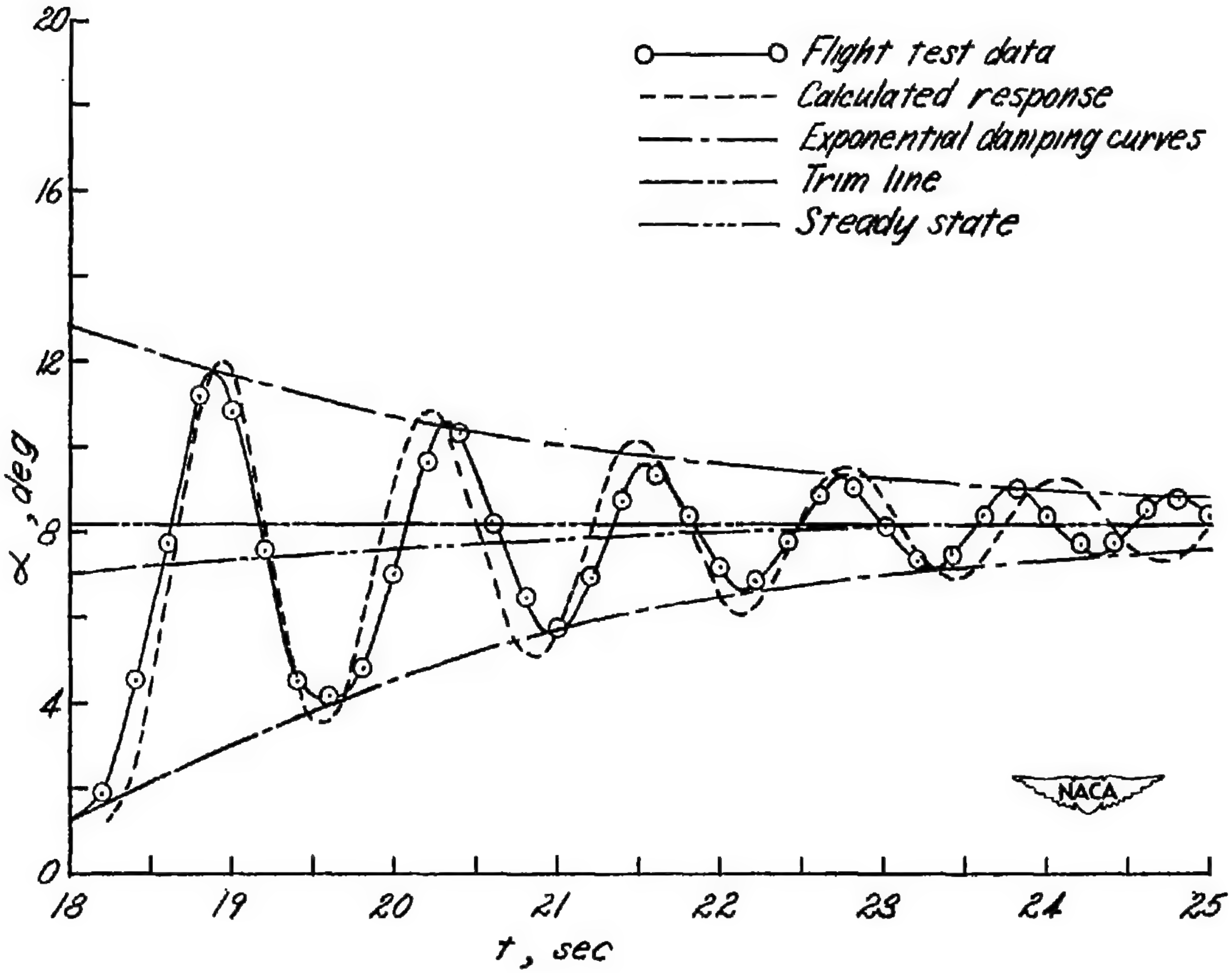


Figure 16.- Variation of total drag coefficient with Mach number for various pulsing conditions for bomb 2.

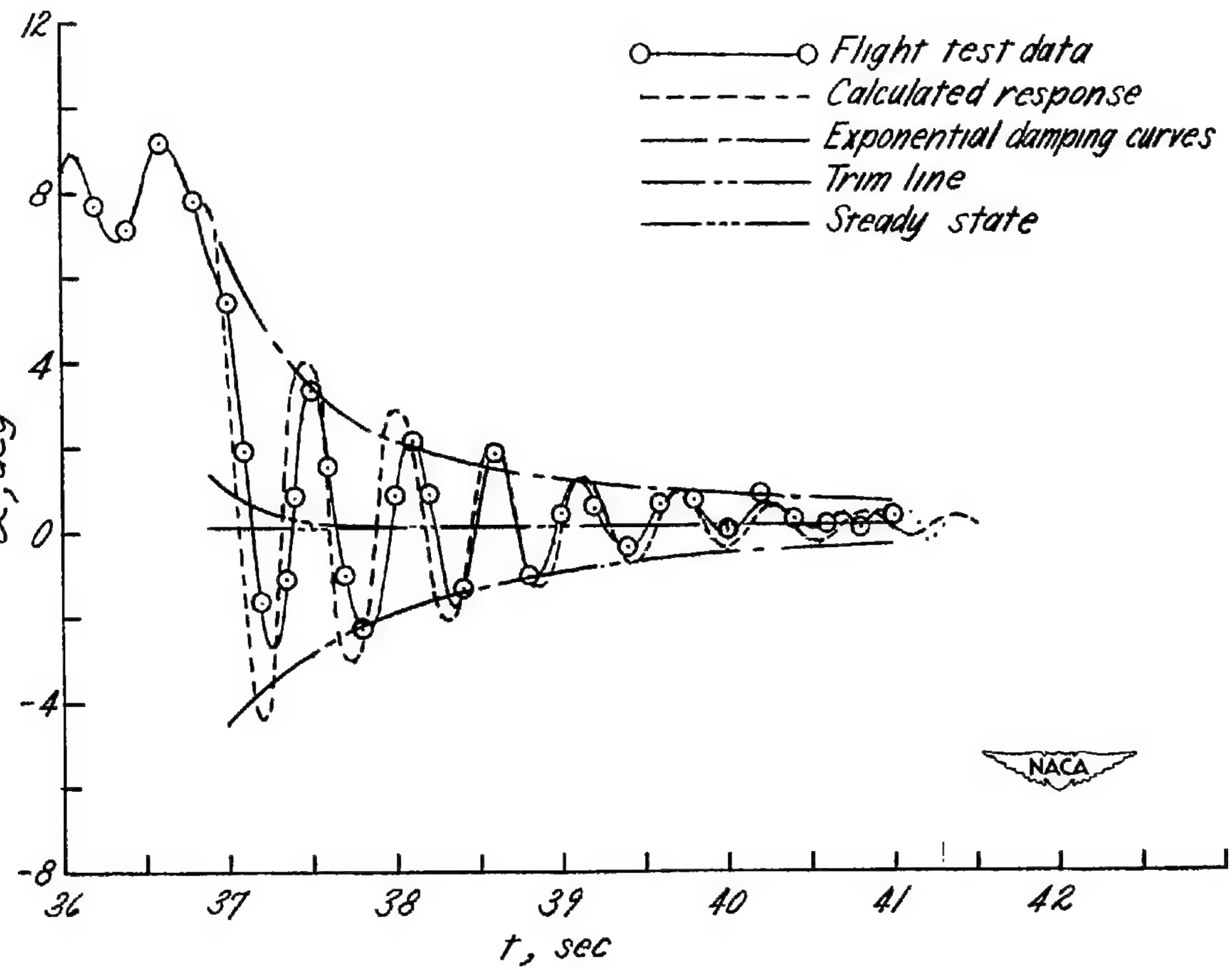
[redacted]



[redacted]

(a) Bomb 1, α response. M = 0.78; V = 785 ft/sec; q = 264 lb/sq ft.

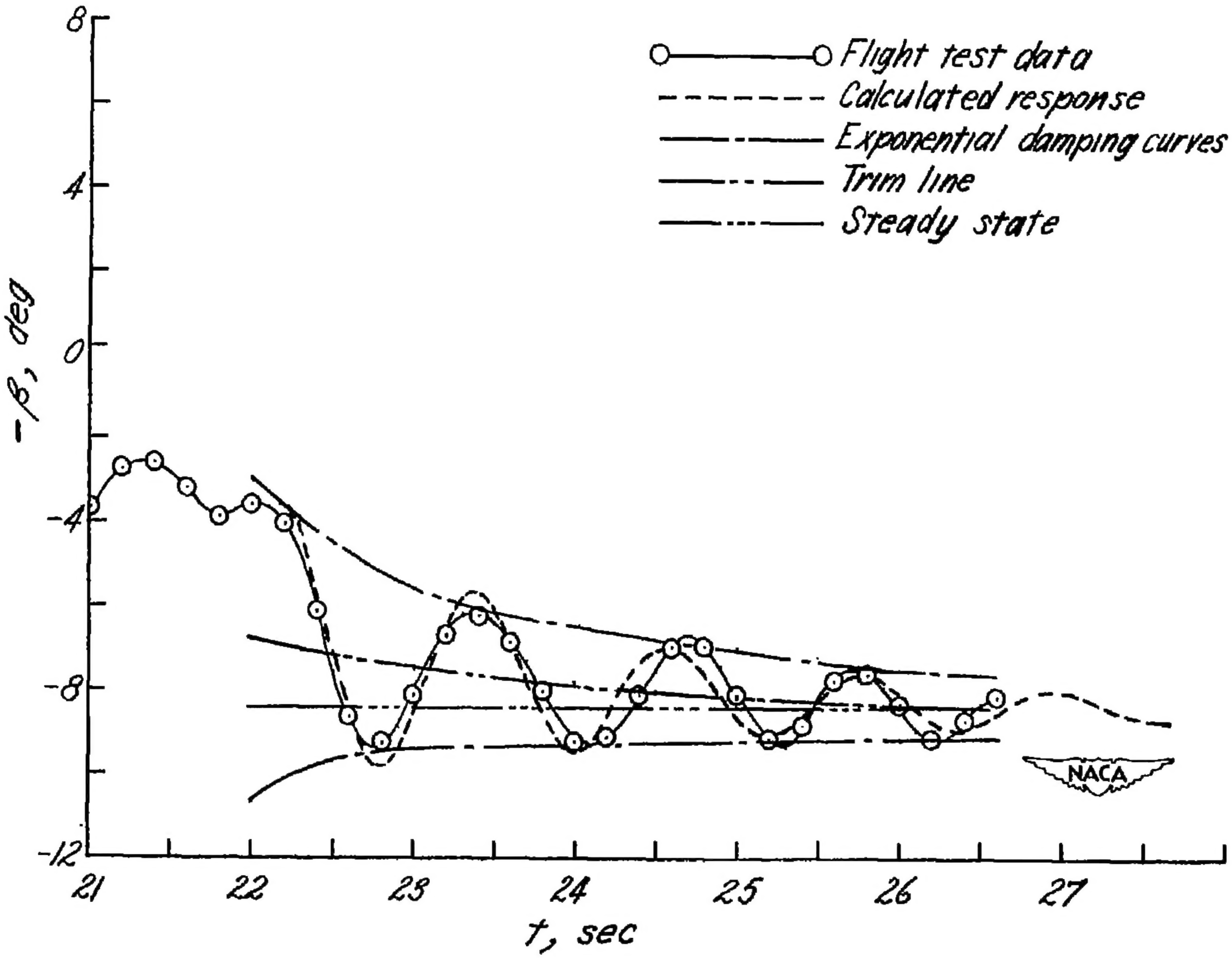
Figure 17.- Comparison of flight-test data with calculated transient response curves.



(b) Bomb 2, α response. M = 0.92; V = 966 ft/sec; q = 712 lb/sq ft.

Figure 17.- Continued.

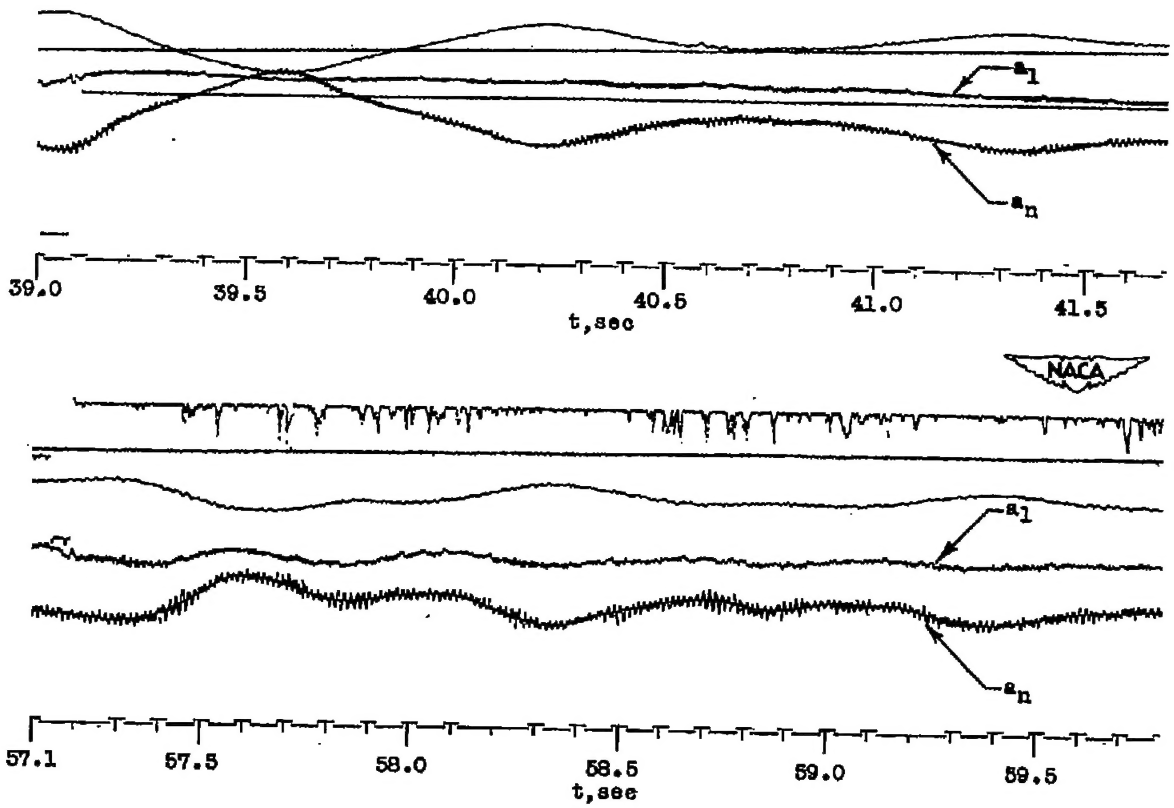
[redacted]



(c) Bomb 2, β response. M = 0.81; V = 833 ft/sec; q = 340 lb/sq ft.

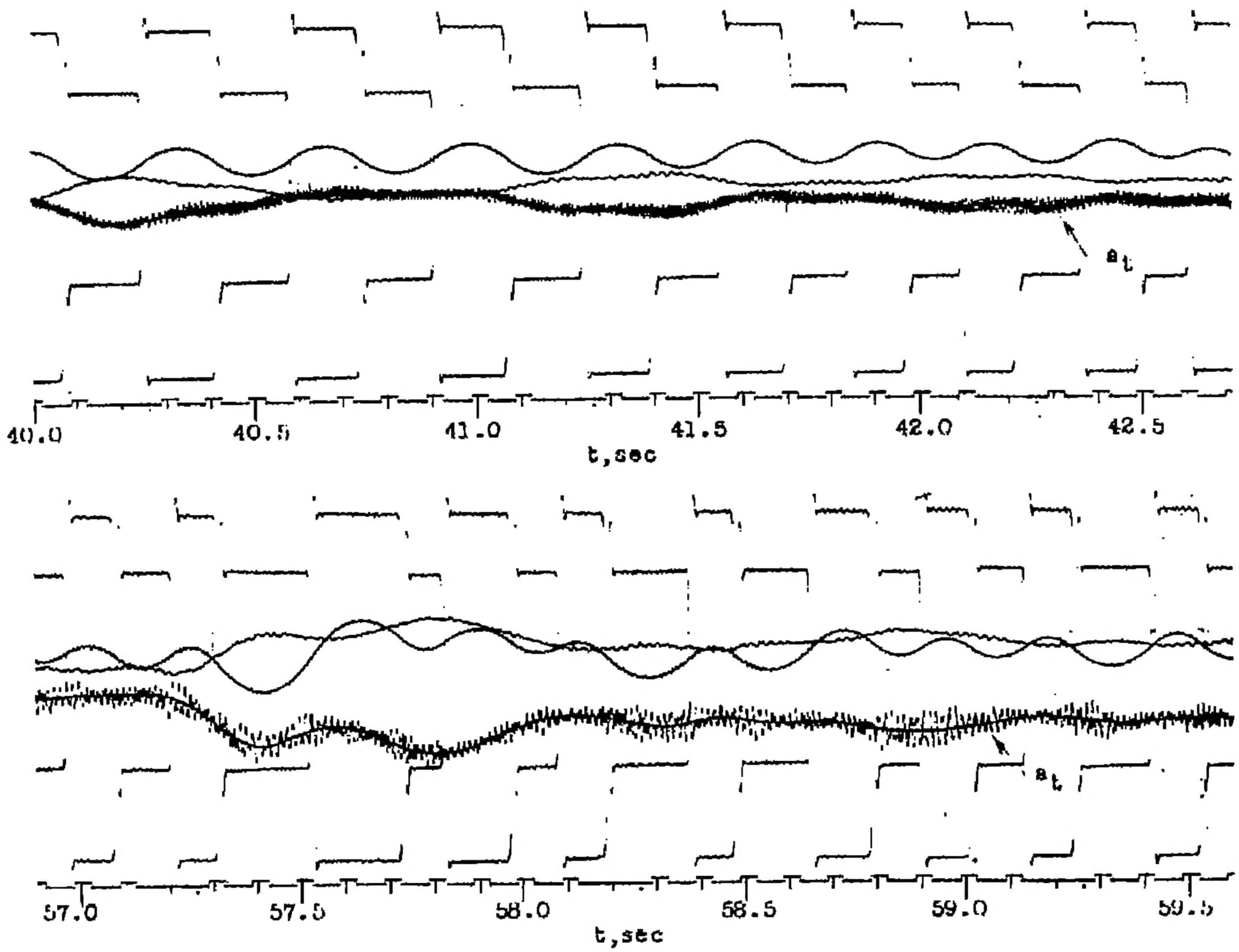
Figure 17.- Concluded.

[redacted]



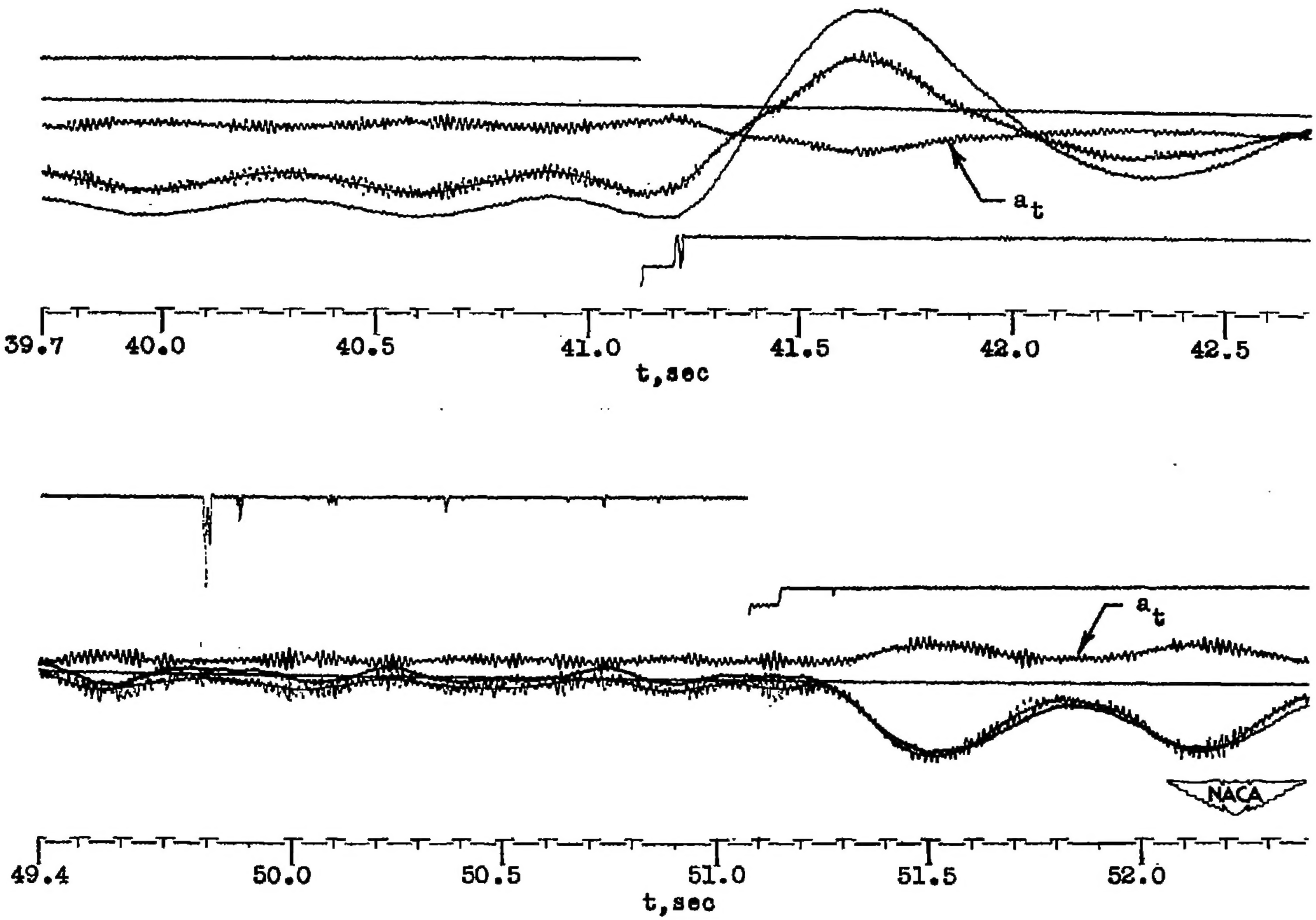
(a) Record showing longitudinal- and normal-accelerometer traces of bomb 1.

Figure 18.- Portions of telemeter records showing high-frequency oscillations superimposed on accelerometer traces.



(b) Record showing transverse-accelerometer traces of bomb 1.

Figure 18.- Continued.



(c) Record showing transverse-accelerometer traces of bomb 2.

Figure 18.- Concluded.